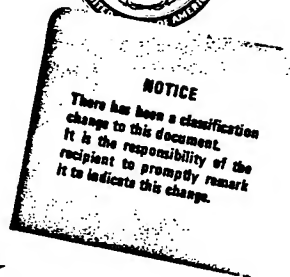


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INSTITUTE FOR DEFENSE ANALYSES
ADVANCED RESEARCH PROJECTS DIVISION
THE PENTAGON
WASHINGTON 25, D. C.

STUDY NO. 1

IDENTIFICATION OF CERTAIN CURRENT DEFENSE
PROBLEMS AND POSSIBLE MEANS OF SOLUTION

This Study was supported by the
Office of the Secretary of Defense, Advanced Research Projects Agency
under Contract No. SD-50

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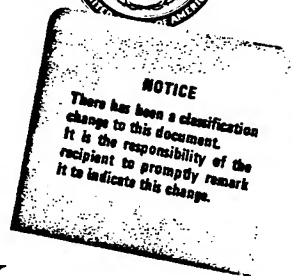
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possible, as first suggested by J. Pasta, to conceive of a computer with a fairly large number of arithmetical units, say a few hundred, if not a few thousand. Such capabilities must alter our traditional approaches to solutions of numerical problems, especially in the field of partial differential equations.

b. For many applications of Monte Carlo-type problems, the structure of arithmetic units is not very efficient. In most applications 10 to 12 bits per number usually suffice. The 16 to 20 bits that are usually available are quite unnecessary.

c. Faster and more complex computers are being designed to extend the range of tractable problems. For none of the computers being commercially produced has the question been raised of the significance, i.e., number of meaningful bits, in the answer or answers. One may imagine that an acceptable procedure might be to describe a number, not only as a fraction and an associated exponent, but with an "index of significance". This brute force approach clearly involves more hardware and control complications, if not some sacrifice in speed. Even so, it is not completely clear what the appropriate rules should be. Some suggestions have already been made, but more study is necessary.

General Recommendation

It is strongly recommended that a group be formed to study these problems and work out a basically new attack on them. It is necessary that the group include not only mathematicians and engineers, but

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Appendix "A"
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TABLE OF CONTENTS

	<u>Page No.</u>
SUMMARY AND RECOMMENDATIONS	1
ACKNOWLEDGMENTS	14
CREATION OF PROJECT 137	15
THE BRIEFINGS	17
REMARKS ON RECOMMENDATIONS	22
CONTINUING IDENTIFICATION OF IMPORTANT NEW PROBLEMS	24
 <u>APPENDICES</u>	
APPENDIX "A" - AREAS OF PROMISE	30
A-1. Chemical Sensing	30
A-2. Information Transmission by Chemical Sensing	34
A-3. Fuel	36
A-4. Transmission of Energy Through Space	42
A-5. Atomic Collision Cross Sections	54
A-6. Matter Under Exceedingly High Pressure	56
A-7. Intense Magnetic Fields	58
A-8. Formation of Concepts Out of Data; and Systems Reliability	59
A-9. ARPA and the Social Sciences	69
A-10. Military Exploitation of Basic US/USSR Differences	71
APPENDIX "B" - ENVIRONMENTAL ANALYSES	76
B-1. Physical Environment of Military Operations	76
B-2. Radiological Mapping and Combat Surveillance	80

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TABLE OF CONTENTS (CONT'D)

	<u>Page No.</u>
B-3. Statistical Data to Plan Fallout Associated With Use of Atomic Weapons by Army Ground Forces	82
B-4. A Radiation Detector for Field Use	83
B-5. Military Geophysics	86
B-6. Detection of Submarines Through Surface Effects	91
APPENDIX "C" - PROJECTS AND APPLICATIONS	93
C-1. Balloon Attacks and Other Non-Conventional Weapons	93
C-2. Development of Breeder Reactors	96
C-3. Undersea Beacons	98
C-4. NAUCRATES DUCTOR	102
C-5. BASSOON	118
APPENDIX "D" - PARTICIPATION IN PROJECT 137	137
D-1. Membership of Project 137	137
D-2. Program of Briefings	139

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PROJECT 137

IDENTIFICATION OF CERTAIN CURRENT DEFENSE
PROBLEMS AND POSSIBLE MEANS OF SOLUTION

SUMMARY AND RECOMMENDATIONS

Introduction

On July 8, 1958, the Advanced Research Projects Agency, with the approval of the Secretary of Defense, asked the Institute for Defense Analyses to set up a Study Work Group, Project 137, ". . . to identify problems not now receiving adequate attention where science can contribute vitally to national security and to recommend agreed technical, and perhaps organizational, means for the solution of these problems." Twenty-three scientists took part in the work of the group during the three-week period, July 14th - August 2d. Through the active cooperation of the Office of the Secretary of Defense and the Army, Navy and Air Force, the group heard outstanding presentations by responsible men on defense problems selected for their urgency. As a result of these presentations and their own discussions and calculations, the members of Project 137 make the following recommendations: (U)

A. AREAS ONLY SLIGHTLY DEVELOPED IN COMPARISON TO
THEIR CONCEIVABLE APPLICATIONS TO DEFENSE

A-1. Chemical Sensing

Techniques exist to detect and identify specific substances at a distance with fantastic sensitivity. These techniques can be greatly improved. Important military applications can be visualized,

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such as determining types and numbers of machines in the vicinity, new types of fuels in use, human concentrations, and getting advance warning of CW and BW attack. An intensive survey of the field should be made. Assuming that it confirms the promise as now seen, recommendations should be made for research within existing government laboratories and for contracts to universities and research foundations. As promising leads develop, a more concerted effort should be made to bring them into practical application by agencies yet to be defined. (S)

A-2. Information Transmission by Chemical Sensing

Coded puffs of radioactivity or chemicals emitted into the atmosphere by a "transmitter" and detected by a "receiver" offer means (1) to transmit coded messages that are obliterated beyond specified distances and (2) to gain new information about micrometeorology. Both applications should be given attention by the person or agency that intensively surveys the whole field of chemical sensing. (S)

A-3. Fuel

Fuel and the fuel supply line interpose massive obstacles against the high mobility demanded by nuclear warfare, and give powerful motivation to produce fuel on the spot. The ultimate system -- not feasible today -- would use small mobile nuclear reactors to generate fuel from air or water, or regenerate a deactivated fuel, for driving the vehicles in the vicinity. Such a system might cut down the fuel supply problem by an order of magnitude. With this aim in view, an appropriate agency should (1) seek out the most advanced thinking at AEC laboratories and

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elsewhere on small mobile nuclear reactors suitable to generate hydrogen from water or regenerate deactivated electrochemical fuels, (2) take a new look at liquid hydrogen as a fuel for existing engines, (3) work towards conceptual design and evaluation of a regenerative electrochemical fuel or other advanced fuel system by stimulating relevant advanced thinking and work on (a) reactor technology, (b) energy storage, (c) electrolytic cells, (d) electrochemical fuel generation, and (e) fuel utilization. This should be accomplished through whatever steps are needed in the way of conferences, work-study groups, arrangements with government laboratories and outside contracts. (S)

A-4. Transmission of Energy through Space

Some encouraging work has been done on electromagnetic and other methods of transmission of energy through space, and ideas are in circulation for more basic approaches to this problem. It is perfectly conceivable that one or another of these approaches will have a vital application such as: supply of power to forward combat locations; operation of drones for reconnaissance or for brute blocking of ballistic missiles; or destruction of targets on the ground or in the air. (S)

In view of the fundamental importance of a workable system of energy transmission, the present status of this field of work should be thoroughly reviewed, a work-study conference should be called to generate new ideas and to arrive at a first assessment of the areas most promising for future work -- particularly work of a truly

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pioneering character -- and steps should be taken to support such work and capitalize on it.

A-5. Atomic Collision Cross Sections

Intensive AEC support of nuclear cross-section measurements has given for atomic nuclei a wealth of data essential for design of nuclear devices. No similar wealth of reaction cross-section data is available for the much older field of atomic and nuclear physics despite its much wider field of application: to communications systems; to missile nose cone physics; to plasma engineering; to controlled thermonuclear reactions; and to chemical reactions in gases. It is recommended that an appropriate agency sponsor a program for the study of atomic collision cross sections. (U)

A-6. Matter under Exceedingly High Pressure

Recent work discloses that some non-metals take on metallic characteristics at ultra high pressures. Further forward-looking work in this field may open a whole new realm of solid state physics and physical chemistry, with conceivable applications to new types of high energy fuel compounds, and is therefore worthy of support by an appropriate agency. (U)

A-7. Intense Magnetic Fields

There is evidence of substantial Russian activity in the area of intense magnetic fields. If strong fields $\geq 10^6$ gauss can be achieved

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this will have important scientific and technological consequences. A symposium on this topic should be arranged soon in order to enlarge the very small number of scientists in the Western world active in this area. (S)

A-8. Formation of Concepts out of Data, and Systems Reliability

A military action is under way. Information comes in of many kinds and of quite variable reliability. Neither in this instance nor in general does any electronic computer, present or planned, know how "intelligently" to formulate significant concepts and conclusions out of a massive volume of information, most of it irrelevant and part of it erroneous. It is a matter of great importance to many aspects of national defense to develop a theory for the formation of concepts under such circumstances, and for the construction of a reliable system out of unreliable components. An appropriate agency should sponsor advanced work in this field by one or more conferences, by contracts, and by such new computation laboratory facility as seems appropriate; and should systematically survey the field for urgently important defense applications. (S)

A-9. ARPA and the Social Sciences

The development of more and more weapons systems does not contribute towards the solution of basic social and policy problems; rather these developments create new problems. The pay-off from contributions that can be made by social science may be greatly in excess of that derived from more hardware development. Hence social

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scientists should be brought into defense problems much more than is now the case. Progress could be made in this direction by selecting for ARPA support certain fields already recommended as highly important by the Subcommittee on Social Sciences and by the Ad Hoc Advisory Group on Psychology and Social Sciences of the Office of the Assistant Secretary of Defense for Research and Engineering. (U)

A-10. Military Exploitation of Basic U.S. and USSR Differences

Differences not only in political ideology but also in the physical, economic and social setup distinguish the U.S. from the Soviet Union. It should be investigated which of these differences can be exploited to our advantage, for example by the design of weapons systems which are most disadvantageous for the Russians to counteract; for example, by imposing a heavy economic strain in particularly vulnerable areas or exploiting the long winters in Russia. There is strong reason to believe that a systematic exploration of this area could yield surprising new ideas. It is recommended that an appropriate agency sponsor a work-study group in this field. (S)

B. ENVIRONMENT ANALYSIS

B-1. The Physical Environment of Military Operations

All weapons systems depend on the physical environment in which they are to be used. It is not sufficient to know the weapon alone, it is necessary to broaden and deepen our knowledge of the respective environment. This is particularly true regarding space, the oceans,

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and radiological fallout. We know too little about the upper atmosphere and about propagation of electromagnetic radiation in space. Many weapons systems under discussion now depend vitally on an increase of our knowledge of these matters. Similar observations apply to the oceans, the ocean floors, and meteorology internal to the ocean. The instrumentation for fallout in the hands of the Army and Civil Defense is inadequate and so is the knowledge of the common man about how to use it. ARPA is urged to pay great attention to this whole complex of questions. For this purpose ARPA might well consider sponsoring many of the functions of the IGY. (S)

B-2. Radiological Mapping and Combat Surveillance

In future conflicts battlefields will have to be surveyed not only optically, but radiologically. While systems are proposed for this purpose, they are too complicated and do not give information to the local commander of small units. It is possible to introduce fairly crude, but cheap and simple instruments with which even platoon or company commanders can determine radiation levels and thereby guide their men safely. Strong emphasis should be given in current planning to radiological mapping and combat surveillance. (S)

B-3. Statistical Data to Plan Fallout Associated with Use of Atomic Weapons by Army Ground Forces

How to lay down tomorrow a desired pattern of fallout is important for an area commander just as it is important for local commanders to know how to lead their troops safely through today's

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battlefield radioactivity. An appropriate agency should sponsor research on:

- a. The statistical variations of winds -- in time, distance, and altitude -- about the values indicated on the kind of measuring equipment that will be used in the field; and on the correlations among such variations;
- b. The planning of measurements for this purpose; and
- c. How to use the results to tell what the military commander can do reliably about securing a desired fallout pattern. (S)

B-4. A Radiation Detector for Field Use

A simple method is recommended for quick conversion of field radios to superimpose occasional Geiger counter clicks on the normal receiver signal so that company commanders and possibly platoon commanders will be immediately and automatically warned of a dangerous increase in radiation level. (C)

B-5. Military Geophysics

The Department of Defense has a vital stake in meteorology and other fields of military geophysics. Techniques to predict in combat zones like Korea whether the second valley over is fogbound or will be fogbound in four hours would change the outcome of engagements. The present unsatisfactory state of military meteorology is a reflection of the retarded and narrow scope of unclassified meteorological research. An appropriate existing agency should consult with Lloyd Berkner, and others closely associated with advanced thinking in this

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field, to determine what should be done to produce an order of magnitude improvement in the present level of forward-looking research in this field and in the amount of young talent attracted to it. (C)

B-6. Detection of Submarines through Surface Effects

Besides the efforts to detect ships and submarines acoustically, electromagnetically, and chemically, more attention should be given to the mechanical disturbance of the water by the propeller action. These disturbances persist for a long time and it should be possible to measure them by suitable instruments. Even deeply-submerged submarines may produce measurable diffusion of "whorls" to the water surface. Studies of the mechanical properties of the sea now in progress should be closely watched and ARPA should be prepared to lend further support. (S)

C. PROJECTS AND APPLICATIONS

C-1. Balloon Attacks and Other Non-conventional Weapons

Very high-flying balloons, carrying megaton weapons, could be used by Russia against this country. They could be released in Siberia or by submarines on the Pacific, their bombs fuze with infrared to go off over our cities. Even when shot down (difficult and expensive), the weapon can be set to go off at any chosen altitude. This is the Japanese balloon scheme of World War II with a vengeance. It is easier for Russia to use it against us than vice versa.

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It is an illustration for the possibility of non-conventional uses of existing weapons, a much neglected field. Sabotage, clandestine operations against SAC, and other possibilities belong in this area which should be quickly and most thoroughly explored with all the aid science can offer, through work-study groups and other effective means. (S)

C-2. Development of Breeder Reactors

The tremendous demands for nuclear power make it necessary for us to learn how to burn all raw materials: not only U-235, but also U-238 and Th-232. The development of breeder reactors, especially for manufacture in large numbers, is exceedingly difficult. Not enough energy is being devoted to this problem. The importance of nuclear reactors for the long term future of the fuel logistics problem (A-3) requires that a much greater effort be made to develop breeders based on both uranium and thorium. (S)

C-3. Undersea Beacons

The great need for communication from deep-lying POLARIS submarines to the continental U.S. can possibly be filled by undersea high-power, unattended acoustic beacons. The submarine would communicate to the beacon at low intensity, thereby programming and triggering a high-intensity output from the beacon. Undersea beacons could also be used for navigational purposes, by submarines or surface vessels. The beacons can be powered by thermal energy derived from fission products such as Ce-144 now available in sufficient quantities in the Hanford

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and Savannah River plant wastes. A conceptual analysis of such beacon systems should be made by an appropriate agency with a view to trial use. (C)

C-4. NAUCRATES DUCTOR, a Very High-Speed Hydrojet Torpedo

A high probability to kill enemy submarines would be provided by a number of nuclear-powered torpedoes covering selected sweep paths at high speeds, equipped with sonar search, homing, and other devices. For this reason, it is recommended that an appropriate agency seek out the most advanced thinking at AEC national laboratories and elsewhere on ultracompact reactors and make preliminary conceptual design studies of a 100-knot to 250-knot hydrojet torpedo with a view to early initiation of further supporting investigations and evaluation of a weapons system built on such torpedoes, for an antisubmarine shield about the U.S. and for other military purposes. (S)

D. Continuing Identification of Important New Problems

The rapidity of scientific advance and the dangers of the present international situation demand a decisively new mechanism to promote contact between the Department of Defense and the scientific community. A minimum response to this need is a program of work-study groups like Project 137 at regular intervals, to identify unappreciated and important applications of science; and other more specialized short-term groups to exploit the possibilities of specified areas of science. For this purpose it is recommended that ARPA set up a Center for Defense Research Work-Study Groups. It is also suggested that ARPA consider how far it might be reasonable to encourage such a Center to evolve towards an Advanced Security Research Institute, where scientists might go on leave of absence from universities, industry and the DOD laboratories together with operational military personnel from the DOD in an atmosphere of study to contribute imaginatively to national strength in a free ranging manner without committing themselves in advance to any specific kind of project, after the pattern of the Institute for Advanced Study located at Princeton, New Jersey. (U)

ACKNOWLEDGMENTS

Called in to look for important unappreciated ways to bring science to bear upon defense, the members of Project 137 received from the Department of Defense a welcome and cooperation for which they are deeply grateful. The Honorable Neil McElroy, Secretary of Defense, and Mr. Roy Johnson, Director of ARPA, impressively stated the urgency of the mission. The program committee and the entire work-study group had the full and active collaboration of the Office of the Secretary of Defense and the Army, Navy and Air Force through the interest of Lt. General Arthur G. Trudeau, Chief of Research and Development, U.S. Army; Dr. Wm. H. Martin, Director of Army Research and Development; Honorable Garrison Norton, Assistant Secretary of Navy (Air) and his Special Assistant, James E. Cross; Honorable Richard Horner, Assistant Secretary of the Air Force for Research and Development; Honorable Paul Foote, Assistant Secretary of Defense for Research and Engineering; Vice Admiral John H. Sides, Director, and Dr. Albert G. Hill, Director of Research, Weapons Systems Evaluation Group; Major General James McCormack, President of IDA; and Dr. Herbert York, Director of the IDA Advanced Research Projects Division. The practical arrangements for briefings and for special contacts with service laboratories as occasion arose were handled efficiently and most helpfully by Lt. Col. James A. Hebbeler and Captain Richard Holden, USN, as well as by the members of the work-study group from the Department of Defense, Dr. Richard Weiss, Dr. Joachim Weyl, Col. Taylor Drysdale and Dr. Orr Reynolds. The members of Project 137 were most impressed with the high ability and sense of dedication of the men from whom they heard, and were most conscious of their vital contribution to the work of the group. To all who helped -- officials of the Department of Defense, officers of the armed forces, representatives of service laboratories, contributors from the National Academy of Sciences and from other non-DOD organizations, IDA officers and Dr. James R. Killian -- the group expresses its deep appreciation. It is also grateful to Col. John W. Keating, Executive Officer of the National War College and Major Paul A. Baltes for facilities and assistance at Fort McNair and to the IDA librarian, F. Koether, who with the cooperation of many agencies gathered together there a valuable working library of classified and unclassified reference materials. Administration of the work-study group was in charge of Mr. Frank Reynolds, Assistant Administrative Officer of IDA/ARPA. Special thanks are expressed to him and to the members of his staff who worked nights, Saturdays and Sundays to help the group. No member of Project 137 can forget the spirit of dedication which animated his colleagues in the group. Almost all had rearranged plans at short notice to take part, in some cases drastically curtailing planned travels or research and teaching schedules. A number of scientists could not take part at such short notice because of previous binding commitments for the period of the study, but expressed their feeling of the importance of the work and asked if they could contribute at some other time or in some other connection.

CREATION OF PROJECT 137

The Advanced Research Projects Agency came into existence by Directive 5105.15 of the Department of Defense, issued in accordance with Public Law 35-325(-7) of 12 February 1953, with two missions: (1) to carry out research and development work on such projects as are assigned to ARPA by the Secretary of Defense, and (2) to recommend to the Secretary of Defense such additional projects as are judged advisable.

In accordance with the first mission, ARPA was assigned in the spring of 1953 responsibility for space technology, advanced missile defence systems and chemistry of propellants.

In accordance with the second mission and with the approval of the Secretary of Defense, ARPA on 3 July 1958 asked the Institute of Defense Analyses to set up a Work-Study Group, Project 137, "to identify problems not now receiving adequate attention where science can contribute vitally to national security and to recommend appropriate technical, and perhaps organizational, means for the solution of these problems and for the continuing identification of important new problems."

In anticipation of this formal Directive IDA had appointed a program committee a few weeks earlier. Beginning on 4 June this committee and Dr. Herbert York, Director of the IDA Advanced Research Projects Division, extended invitations to a selected group of widely known

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scientists to participate in this work for the three-week period --
14 July - 2 August 1953.

The final group (Appendix D) included the leader of the group that detected the neutrino; associate directors of research of two large corporations and of one major AEC national laboratory; an expert in differential equations; an aerodynamicist; the economist whose writings revolutionized the concept of optimal strategy; leaders in the chemical separation of plutonium, in physical chemistry, and in the development of antimalarial drugs; workers in advanced areas of theoretical physics and elementary particle physics; the statistician who initiated the ultra lightweight DAVY CROCKETT atomic weapon; and the leading expert on nuclear reactors, recently president of the American Physical Society. All had previously had contact with phases of national defense. In addition to these 22 members from outside Washington the group included four experienced members from the centers of science-defense planning of the three armed services and from the Office of the Assistant Secretary for Research and Engineering. The majority of the 26 participated for the full 3-week period. All members were cleared for access to Top Secret material.

The National War College, Fort McNair, Washington, D. C., housed the work of Project 137: briefings in the mornings; discussions, study of reports, calculations and writing in the afternoons.

THE BRIEFINGS

More important to the work of the group than any other single factor were the outstanding presentations of urgent issues made to it by serious and responsible men. It cannot be stressed too much what a powerful impetus it gave to Project 137 scientists to hear from men who know and care deeply about defense problems.

To assist the program committee in focusing the efforts of the group, the services made a first selection of issues, coming to a total of 50. From these the program committee made a second much narrower selection for the final briefing program (Appendix D). The total number of problems of deep concern to the services is obviously much more than a single work-study group can review for unappreciated applications of sciences in a single three-week period. Project 137 can, therefore, be regarded as a single sample well drilled into an enormous and ever-growing oil field. The output gives an accidental and rather hit-or-miss measure of the much more still underground. Great areas went unexamined. The group was regretful about the many outstanding presentations already worked up for Project 137 for which it was impossible to make time in a program properly proportioned between hearing and working.

Speakers with many other heavy burdens accepted with good will the cryptic advance advice, "Stimulate group to invent ideas and identify issues important and challenging enough to serve as nuclei about which

subsequent scientific work can concentrate. Communicate intense motivation about important problems. Purpose not to hear all problems under control, will be solved in short time, only need more money. Tell what causes responsible people sleepless nights... (Seek) not 10% improvements on existing ideas but entirely new developments. Informal -- much opportunity for interruption and discussion. ...A briefing is a success if the problem it posed is thereafter every afternoon the center of intense analysis by a knot of participants."

Some presentations, at the request of the program committee, concentrated on military problems to which technical solutions are desired and others concentrated on technical work in progress or technical problems. The group was impressed with the great amount of high-quality work presently going on at many service laboratories and associated agencies. The impression could not be escaped that the scientific community represented by the Department of Defense has great ability and a scope that far transcends the subject matter coverage of any university or any industrial laboratory.

Many members of Project 157 were deeply disturbed and others even shocked by the gravity of the problems with which they found themselves confronted. These men in number constituting less than 1/4000 of America's scientific community have been stimulated to intense activity by what they heard. The opinion is unanimous that briefings of this high caliber -- plus back-and-forth discussion -- recorded on film and sound track and replayed to carefully selected groups from universities, indust

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and defense and other national laboratories would do much to direct attention and productive output from less urgent issues to problems more important for the national security.

Under the impression of the problems presented, and from a study of many of the documents made available in the library, the group has developed a strong feeling for and deep appreciation of, the great crisis with which the nation is faced. The group senses the rapidly increasing danger into which we are inexorably heading. In our view the crisis shows up in all fields: military, scientific, economic, and social.

Among issues in the defense picture, the briefings pointed up the following as being particularly important:

a. The extraordinary technical difficulties of detecting, identifying and destroying enemy submarines. This gives added significance to our own POLARIS system which, however, to the group's concern, is still beset with many problems of its own and is judged by many with whom the group talked to be planned on too small a scale.

b. The need for a jam-proof world-wide military communications system, capable of issuing completely reliable orders, particularly for two-way underwater communication.

c. The high degree of development in Russian radar equipment, exceeding ours in several instances, as disclosed by the observations of the Navy's "big dish" radio telescope (one of the most promising American detection devices).

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d. The necessity of a dual capability of the Army for nuclear and conventional war. The tactical and strategic problems of this two-fold capability are clearly unsolved. The logistic difficulties are also not overcome. Those generated by the enormous fuel demands and very long pipelines are the most outstanding. The mobility of the Army is too low for the type of dispersed engagements that have to be expected, despite all the efforts made to improve it.

e. The need for realistic reappraisal of policies, including public information, on chemical and biological warfare -- presently a seemingly forbidden topic.

f. Local air defense of military targets is not being exploited as fast as appears possible even with present budgetary limitations. Local defense of civilian targets is being pushed but in view of the fallout problem will be of little value. The possible interference between the present NIKE batteries and offensive SAC operations during an attack on this country has not been solved.

g. The high degree of vulnerability of SAC in spite of efforts made to decrease it.

h. The rising power of Russia in scientific, technological and military affairs. Not only did the group learn about an already existing superiority in many areas of individual weapons, e.g., tanks, missiles, and electronic equipment, but in other areas it was found that our present advantage was rapidly being overcome. The group was also disturbed by the approximately two-to-one advantage of Russian research, development

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and production lead action.

1. The complete absence of any passive protection of the civilian population.

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REMARKS ON RECOMMENDATIONS

Confronted by problems of such scope and a very limited time, the group concentrated on ways science can help, pushing aside all questions of strategic and management and financial analysis as lying outside their directive and outside their working interests. The final subject-matter recommendations fall into three groups in the Summary and Appendices:

A. Areas of advanced research (A-1 to A-10), such as chemical sensing and radically new types of electrochemical cells, which at present are only slightly developed in comparison to their conceivable applications to defense.

B. Environmental analyses (B-1 to B-6): broad and already familiar fields of research, such as meteorology, which impinge vitally on military actions in important ways and should therefore be vigorously supported and imaginatively monitored for potential military applications. In the same class belong oceanography, geophysics and materials analysis, the group felt, but Project 137 made no formal recommendation to this effect because of insufficient time to consider these questions in any detail.

C. Projects and applications (C-1 to C-5), such as BASSOON and NAUCRATES DUCTOR, which already suggest fairly specific military systems and which for the most part can probably be best handled through existing defense agencies by a project type of organization.

It may well be that a few of the recommendations made by Project 137 are not new, despite efforts made to check on work currently in progress. It may even turn out that one or two of the ideas are already being pursued energetically and imaginatively in projects of which the group is not aware. The history of science is well known to demonstrate that practically no idea is ever completely new. However, it also shows, as for example in Mendel's discovery of the laws of inheritance, that several decades may sometimes elapse between the moment when a new idea is conceived and the time it is put to use. The group conceived its function was, not to make more discoveries, but, to help shorten the interval between discoveries on hand and their application.

To bring about the recommended new developments in many cases the group has suggested specialized work-study groups of limited size and of duration ranging from a week to several months, as appropriate. No procedure is known which can secure in peacetime the same combination of specialized knowledge, outstanding ability, active imagination, judgment, and intense motivation. The presumptive sponsor in many cases would be ARPA, in other cases other appropriate agencies of the DOD. The follow-up (work in defense laboratories, outside contracts, steering committee, review of results for immediately important applications, project organization) would be expected to be the responsibility of the sponsoring agency.

CONTINUING IDENTIFICATION OF IMPORTANT NEW PROBLEMS

The group was asked to recommend means for the continuing identification of important new problems - areas where science can be used in unappreciated and vital ways to strengthen the country.

The tremendous technological changes already made as well as those coming fast up over the horizon make it difficult for the services to adapt themselves to these developments. In their efforts constantly new, unexpected scientific problems are encountered, ranging over all the sciences.

Many of these touch on such fundamental issues that the continuing assistance of scientists fully familiar with the very latest progress of their disciplines is required.

Methods must be found that go well beyond the existing types of contact and interaction between the DOD and the scientific community. The group has considered possible ways to provide a mechanism. Its principal aim would be, on the one hand, to introduce scientists not now working on defense problems into these areas and on the other to give scientifically trained military officers of the three services and scientists working in defense laboratories an opportunity to bring their vast experience to bear on the selection and study of the problems to be answered.

Two mechanisms received much attention from the group. One, a Center for Defense Research Work-Study Groups, would provide:

a. A very small but highly competent staff to take the major burden of handling classified scientific work-study conferences for ARPA and other defense agencies.

b. Secure meeting rooms for ever-changing groups of limited size, nearby work rooms, and places to eat, walk and sleep without going outside the guarded area, and surroundings under whose influence it is a pleasure to work. Such a place does not now exist in the Washington area. To provide such a place would make it possible for a group to do substantially more in a limited time, as witness the outstanding Gordon Research Conference.

c. A good small working library of classified and unclassified reference materials.

d. Simple computation facilities.

e. Proximity to an excellent library and to a university with excellent departments of science.

f. Facilities for reproducing unclassified and classified materials.

g. Contact office in ARPA to deal with flow of information and reports, clearance for visits, and scheduling of visits.

h. Proximity to Washington so responsible Washington people can contribute with the same effectiveness from which Project 137 benefitted.

i. Operation by such an agency as a non-profit defense research organization of high standing or the National Academy of Sciences to guarantee to the Center a continuing prestige among scientists, among the services, and service laboratories, so that anyone invited to take part in the work of the group can consider it an honor to be able to come.

j. An ever-changing program of specialized work-study groups in response to identified needs.

k. A regularly programmed repetition every six months of something with the scope and problem identification responsibility of Project 137 as a minimal response to a pressing need.

The other mechanism, an Advanced Security Research Institute, would

a. Include the Center for Defense Research Work-Study Groups and perhaps evolve out of that Center.

b. Provide a place where scientists can go on leave of absence from universities, industry and the DOD laboratories together with operational military personnel from the DOD in an atmosphere of study to contribute imaginatively to national strength in a free-ranging manner without committing themselves in advance to any specific kind of project. The Princeton Institute for Advanced Study would serve as a model.

c. Consist of members and visitors. Both groups would be cleared and much of the work would be classified. The nine or more members would have terms from perhaps 1 to 5 years, would be selected from a variety of fields, and would assist in planning problem identification meetings like Project 137 and otherwise

search for new applications of science and solutions to urgent problems of defense.

d. Provide a center for visitors coming for periods from a month to a year either sent by defense laboratories and other institutions under arrangements mutually agreeable to all three parties or otherwise invited to participate.

e. Have for foundation of its work ready access to information and briefings by the DOD and the scientific community.

f. Conduct such seminars as seem appropriate; serve as a free market place of ideas with much of the student teacher relationship; possibly promote and edit a classified journal common to the area of science and defense.

g. Have appropriate computers but minimal laboratory facilities.

h. Have no contract award functions, have no supervisory function, have no assigned tasks, have no responsibility with respect to national science policy, be no place of reference for organizational questions. Its daily grist would be the technical problems of science and defense; it would be a full-time activity.

i. Provide a means to expose high scientific talent, not now occupied with defense activities, to defense problems, without diverting talent permanently from the pressing basic research needs of the USA.

As between the Center and the Institute opinions in the group were divided. However, no question existed that a decisively new mechanism must be found to promote closer contact between the DOD and the scientific Community. It is the feeling of the group that a Center for Defense Research Work-Study Groups, or something like it, is a minimum response, and that efforts should be made to move as far beyond it in the direction of an Institute as those more familiar with national science policy deem wise. ARPA has the power to bring the much-needed new activity into operation, and ought to move promptly to do so.

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APPENDICES

Appendix "A" - Areas of Promise

Appendix "B" - Environmental Analyses

Appendix "C" - Projects and Applications

Appendix "D" - Membership of Project 137 and
Program of Briefings

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STATE OF PROMISE

A-1. CHEMICAL SENSING

Introduction

The ability to identify airborne or waterborne chemical species in extremely low concentrations would be a powerful asset for both military and civil goals. It is difficult to visualize any natural or man-made process which does not put some kind of "signal" into the air in the form of a few (or many) molecules or atoms which may be characteristic of that particular process. Hence the possibility exists for diagnosing activities of various kinds at a distance. This proposal is simply to stimulate basic research in selected areas yet to be determined with the aim of pressing existing analytical tools to their ultimate sensitivity and, if possible, to devise new specific methods. There is no single system for chemical analysis, so it is unlikely that any single technique will be applicable to problems of a wide variety. However, a few suggestions will be given merely as illustrations. It will be seen that none of these approaches is new but nevertheless with adequate incentives for understanding there is reason to believe that new and important results can be obtained.

Illustrative Examples

We may start by recalling biological systems. It is rather well established that the olfactory sense detects and identifies specific substances with fantastic sensitivity. The male gypsy moth can detect the female by olfaction over a 2-mile range and it is estimated that only

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Appendix "A"
IDA-ARPA S-1

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1,000-10,000 molecules of some substance per cubic centimeter of air is the signal. The olfactory sense of a wide variety of animals, including fish, seem to be similarly acute. Briefly stated, it would be of great interest to understand how they do this, and to make use of the discovered principles either by using biological systems as detectors or by devising artificial systems employing these principles. There has been rather diffuse effort on this problem over the years but most of the results have simply described the phenomenon, and only a relatively small amount of research has been directed toward a fundamental understanding.

Modern instrumental techniques which determine characteristic atomic and molecular dissociation and vibration frequencies have revolutionized many areas of chemistry. Under the generic title "spectroscopy" one thinks of infrared, vacuum ultraviolet, microwave, and still other forms of molecular probing which have great sensitivity by previous standards. "In a molecular beam some molecules can be detected with a sensitivity of one per second, with the result that observation of a few thousand per second is easy" (Zacharias). It is highly likely that several of these methods can be pressed to a sensitivity much higher than presently achieved. It might also be mentioned that we do not know but that existing techniques are already adequate for obtaining certain information of value. For example, we have learned that the Chemical Corps is already employing infrared spectroscopy to obtain advance warning of certain "nerve gases".

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Appendix "A"
IDA-ARPA S-1

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It did not seem worthwhile to the members of Project 137 to try to think of other approaches themselves because in the time available it was impossible to cope with the breadth of this problem. An analogue might be mentioned showing what has been done in another field where sensitivity and selectivity are inherent qualities. The radiochemical analysis of atomic bomb debris carried through the air halfway around the world has resulted in very detailed diagnosis of weapon type, yield, materials of construction, and so forth. If one could devise chemical identification of nonradioactive substances with anywhere near this sensitivity, it is not hard to visualize important applications; for instance: types and numbers of machines in the vicinity, new types of fuels in use, advance warning of CW and FW attack, human concentrations. It might also be mentioned here that the general problem of chemical sensing has already been considered briefly in the DOD Report of the Ad Hoc Group on Atmospheric Electricity, RD 299/13 (15 Dec 1956).

Specific Recommendations

Some person or agency should survey the present status of this field in order to formulate the following:

- a. Definition of techniques of high sensitivity and specificity.
- b. Catalogue of research already in progress bearing on the problem.
- c. Research workers who could contribute to a future program.

Appendix "A"
IDA-ARPA S-1

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d. Specific applications of interest to Department of Defense.

Based upon the results of the survey, recommendations should be made for research within existing government laboratories and for contracts to universities and research foundations, and for a conference for the exchange and stimulation of ideas.

As promising leads develop, a more concerted effort should be made to bring them into practical application by agencies yet to be defined.

A list is given here of areas of science and technology where one might turn for information on this problem:

Chemoreception in insects and other animals	V. G. Bethier, Johns Hopkins E. S. Hodgson, Columbia A. J. Haagen-Smit, Cal Tech
Insect repellents and attractants	Stanley Hall, USDA, Beltsville
Molecular spectroscopy	Many people in many laboratories
Air pollution problem	Center of much fundamental work in Los Angeles area
Microchemistry	E. P. Cunningham, Univ. of Calif.

I. Perlman
R. M. Joyce
C. S. Marvel
F. Wall

Appendix "A"
IDA-ARPA S-1

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A-2. INFORMATION TRANSMISSION BY CHEMICAL SENSING

Two kinds of information can be secured by chemical sensing:

(1) the concentrations of specified molecular species at a given instant of time and (2) how this concentration varies with time. A few of the many conceivable applications of (1) have already been mentioned. Observations of the time variation (2) can also be visualized to secure information from foe or friend; for example, to count the number of enemy vehicles passing a given point; or to receive signals from one's own forces under special conditions.

To give an illustrative example, imagine a radioactive material which is emitted in discrete coded puffs from a "transmitter". The "receiver" is a radiation detector, say a Geiger counter. This system of information transmission could obviously be generalized by emitting simultaneously two or more types of radioactive substances, and providing the detector with energy discrimination.

The information so transmitted has the unusual feature that it is washed out by atmospheric mixing after passage over a certain distance, which can be adjusted by varying the length of the individual puffs.

The analysis of this loss of coherence, or information content, is a problem interesting on two counts. (1) more information about

Appendix "A"
IDA-ARPA S-1

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the mixing process would assist in the first conceptual analysis of a puff-type information transmission system; (2) the study of the diffusion and convection of individual puffs of radioactive or chemical tracers would add to our understanding of micrometeorological processes.

Specific Recommendations

As part of the task of the person or agency that first surveys the field of chemical sensing as a whole, attention should be given to puffs of radioactivity and chemicals (1) as a way to transmit coded messages that are obliterated beyond specified distances and (2) as a means to increase understanding of micrometeorology. For this purpose it would be appropriate to secure the assistance of an imaginative expert well recommended by Dr. Barry Wexler, U.S. Weather Bureau - Dr. George Shortley, Fort Detrick, Frederick, Maryland, or Professor Sutton, consultant to Fort Detrick.

F. Kellie

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A-3. FUEL

The presentations we heard laid heavy stress on the burden of supplying fuel to military operations at advanced locations. The American army advancing across France into Germany consumed 400,000 gallons a day. In Korea fuel constituted over 55 per cent of the logistic load. The army of the future, planning on nuclear warfare, must and does seek a mobility higher than ever before. Against achieving such mobility the demands of fuel and the fuel supply line interpose massive obstacles.

No technical problem of the modern army has higher priority, nor offers a greater challenge to science and technology, than fuel supply.

No solution of the fuel problem is acceptable which does not recognize the many military requirements on the many kinds of vehicles that are going to use the fuel. It is evident that petroleum fuels have many virtues. Any alternative must be at least equivalent operationally. In addition, it must reduce the logistic load if it is to merit consideration for general field use.

From the evidence available to us in a cursory review it appears that there is vigorous and imaginative research in progress on many facets of this problem in both industrial and government laboratories.

Appendix "A"
IDA-ARPA S-1

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However, we believe that new scientific principles must be developed through pioneering research before fuel logistics can be substantially simplified. That this point is recognized shows in the support of research on such a subject as free radicals, and work on fuel cells for direct conversion of chemical energy to electrical power. We believe that the importance of the fuel problem demands continued and increasing support of research in such designated areas of science and technology.

To be able to generate fuel locally rather than ship it in would be a great step forward. We do not see how to do this, but we can see directions of investigation that might ultimately open the way to such a localized fuel system. The system would be centered about mobile power supply units, such as mobile nuclear reactors. The reactors would produce fuel for the use of vehicles in their localities. From this point on the system would differ accordingly as the fuel is burned or merely degraded to an energy-poor form that would later be regenerated at one of the power sources to the original energy-rich form.

The combustion type of system would be designed to generate fuel from locally accessible and universal raw materials: air or water. This system would lead to fuels such as hydrogen peroxide, methanol, or hydrogen (gas or liquid). We made contact with

Appendix "A"
IDA-ARPA S-1

31 -
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promising secret NACA experience on driving jet planes with liquified hydrogen for fuel (RME 57F 13a, -14, -19a and related NACA reports). We found that the storage tank weight relative to the fuel weight is no more for liquid hydrogen than it is for gasoline. We were informally advised by NACA workers that the same fuel can probably be used without great difficulty in existing reciprocating engines such as drive most ground equipment. Practical experiments with such equipment modified to liquid hydrogen fuel have not come to our attention and deserve consideration. The techniques for simple safe use of liquid hydrogen have made enormous strides since 1952, giving occasion for a fresh look at this fuel for use with existing vehicles.

Among regenerative fuel systems perhaps the greatest long-term interest attaches to an approach that is not feasible by today's technology: electrochemical generation of fuel - preferably generation of a pair of liquid reactants, A and B, out of a liquid or solid degradable C. Vehicles would trade in C when being tanked up through separate ports with A and B. No chemical fuels would be brought into the area of hostilities. In case of protracted operations it might be necessary to bring in new fissile cores for the nuclear reactors used to regenerate the chemical fuel. All vehicles would be powered by electric motors. In this connection, it is interesting to note that some modern ~~naval~~ ~~land~~ ~~air~~ equipment (Le Tourneau - Westinghouse) has four-wheel electric drive.

Appendix "A"
IDA-ARPA S-1

35
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There is no reason to believe that a practical electrochemical fuel system, if it can be developed, should be limited in application to the high priority goal of military mobility. Civilian application might be forced by rising costs of conventional fuel for motor transport. In such an application the filling stations might look familiar but the fuel they sold might for the most part be regenerated locally. The electric power for this purpose would come from stationary nuclear reactors suitably spaced over the country.

Four vital facts stand out about electrochemical energy:

- a. electric drive has unique simplicity, reliability and flexibility;
- b. mobile reactors can regenerate electrochemical sources;
- c. pound for pound electrochemical sources can store as much energy as gasoline; and
- d. this stored energy can be converted into power at the wheels with an efficiency much higher than the corresponding efficiency for gasoline.

The central problem is the electrochemical cell. Despite great improvements, today's cells:

- a. are too heavy,
- b. have a too low current capacity.

Intensive development work has gone on and continues to go on, but its goals are improvements of a few per cent, not radically new approaches.

Appendix "A"
IDA-ARPA S-1

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Such approaches demand quite a new kind of research. As H. K. Ziegler has remarked, "Extensive research in the field of electrochemical kinetics could be expected to yield valuable results. Moreover, only a small number of the possible variety of electrochemical systems have yet been investigated."

Among points worthy of special investigation would seem to be the following:

- a. Systems powered by liquid electrochemical reactants.
- b. Physical mechanisms for securing large reaction surface and yet preventing irreversible combination of the reactants (emulsification with organic separator films; bubbles; techniques familiar from flotation processes in mining; cavitation; jets of one liquid going into another; barriers).
- c. The fundamental theory of the maximum rate of nearly reversible electrolysis that is, in principle, possible. From this theory one would seek to determine the basic physical parameters with which advanced cell design should concern itself.

Specific Recommendations:

An appropriate agency should:

- a. Back out the most advanced thinking at AEC laboratories and elsewhere on how small and how mobile it may be conceivable ten years hence to construct electric power generating reactors with a view to conceptual analysis of an advanced fuel generating system.

Appendix "A"
IDA-ARPA S-1

- 40 -
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b. Seek advanced thinking on what a reactor could do if it were designed for production of hydrogen at the optimum rate directly from water rather than via electrolysis;

c. In the light of this information and experiments on liquid hydrogen powering of existing equipment, determine under what special conditions, if any, a hydrogen-fuelled system might make sense;

d. Determine what individuals and institutions are in the best position to contribute radically new and imaginative ideas to the theory and design of electrolytic cells, and

e. Take whatever steps are needed in the way of conferences, work-study groups, arrangements with government laboratories and outside contracts to stimulate the generation of worthwhile advanced ideas on:

- (1) reactor technology;
- (2) energy storage;
- (3) electrolytic cells;
- (4) electrochemical fuel generation; and
- (5) fuel utilization.

and to forward work on them leading towards the conceptual design and evaluation of a regenerative electrochemical fuel or other advanced fuel system that might drastically cut down the fuel supply problem.

R. M. Joyce
C. S. Marvel
I. Friedman
P. T. Wall
J. A. Wheeler

Appendix "A"
IDA-ARPA S-1

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A-4. TRANSMISSION OF ENERGY THROUGH SPACE

The group heard of work in progress on electromagnetic methods of transmission of energy through space, intended for destruction of either ground targets (River Styx Project) or incoming missiles (Project Cindy). Other motivations are also obvious for seeking means to transmit energy through space: to supply power to forward combat locations; to operate reconnaissance drones; and to sustain swift high-altitude drones for blocking ballistic missiles. It would be as difficult to catalog all the applications of a practical transmission system as to try a hundred years ago to list all the uses of electricity. At this point one can only pass the judgment, "potentially extremely important."

To look at applications, and to seek to reach them primarily by pushing existing approaches to the limit, may very well lead to very worthwhile advances. However, if past history is any guide, it would appear that the chances to turn up something new and promising would be increased by also looking into fundamental principles and examining new conceptual combinations without trying to visualize any specific application in all detail.

Little time was available to review the well-known fundamental principles or to look into new combinations. Therefore, the following comments are offered only as a limited survey of the field of energy transmission, to highlight some of the challenging questions and to suggest a few directions in which effort might prove especially worthwhile.

Appendix "A"
IDA-ARPA S-1

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Electromagnetic Radiation

Electromagnetic radiation is a reasonable basis for a system of energy transmission:

- a. the principles of propagation are well understood;
- b. the radiation can be transmitted to great distances and directed;
- c. the technology of generating radiation has had considerable development;
- d. electrical circuits offer a more flexible technique for handling power than do any other known methods.

For transmission over distances between 1 km and 20 km the absorption of the atmosphere affects the choice of wave length as shown in Table I.

Table I

Wave Lengths, λ Transmissible in the Atmosphere Below the Ionosphere. Figures calculated from tables in "Propagation of Short Radio Waves" edited by D. E. Kerr, McGraw Hill Book Company, New York, 1951.

	50 per cent loss permissible over 1 km path (3 db/km)	10 per cent loss permissible over 20 km path (2 x 10 ⁻² db/km)
Clear weather transmission sufficient	$\lambda \geq 0.18$ cm (but not in the immediate neighborhood of 1/4 cm and 1/2 cm); also optical and near infrared	$\lambda \geq 2$ cm; also optical and near infrared
All weather transmission required	$\lambda \geq 1$ cm	$\lambda \geq 8$ cm

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Appendix "A"
IDA-ARPA S-1

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At greater distances the meteorological complications of the atmosphere make proper beaming of the energy increasingly difficult even when the path of transmission runs more than 100 meters above the ground layer of air. Beaming also demands a narrow diffraction pattern and, therefore, a sufficiently large antenna (Table II).

Table II

Minimum Diameter, D, of Transmitting and Receiving Antennas of Equal Sizes and Uniform "Surface Emissivity" Required to Reduce Additional Losses by Diffraction Below the Specified Upper Bound.

Condition	50 per cent diffraction loss at 1 km	10 per cent diffraction loss at 20 km
5 x 10-5 cm (visible) clear weather	D = 4 cm $\lambda = 0.18$ cm, D = 2 m $\lambda = 1$ cm, D = 5 m	D = 1 m $\lambda = 2$ cm, D = 200 m $\lambda = 8$ cm, D = 400 m

Note: All D values are rough estimates.

The effective area of the two antennas can, in principle, be decreased below the indicated limits by a design that does not assure uniform flux of high frequency current over the antenna surfaces. The optimum design depends upon the kind of criterion of "effective area" that is relevant.

A fantastically high upper limit is set to the power density that can be transmitted by reason of the breakdown strength of air for static fields, of the order of 30,000 volts/cm:

- 44 -

Appendix "A"
IDA-ARPA S-1

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(surface density of power emission)

$$\begin{aligned} &= (\text{velocity of light}/8\pi) (100 \text{ electrostatic volts/cm})^2 \\ &= 10^{13} \text{ ergs/cm}^2 \text{ sec} \\ &= 1 \text{ megawatt/cm}^2. \end{aligned}$$

The actual limits are substantially less than this figure due to the frequency dependence of breakdown field strength. However, the power levels that are in principle attainable for antennas of reasonable size are in any case enormous.

A radiative output of 1 Mw/cm^2 can be obtained from a thermal source only at temperatures over 25,000 degrees Kelvin. Therefore, attention is drawn away from incoherent thermal radiation to monochromatic radiation in seeking for high intensity sources.

An idealized antenna for the emission of monochromatic radiation might be visualized as consisting of two sheets of current, uniform in density, over the antenna surface, separated in space by a quarter wave length, one oscillatory current lagging in time by a quarter period with respect to the other. At a third the critical field strength ($1/3$ of 100 electrostatic volts per cm, or $1/3$ of 100 gauss) and at a tenth the associated power level - that is, a little over 100 kilowatts/cm² - each sheet must have a surface density of current of 6 amperes per cm. To drive the oscillatory current against radiative resistance requires a field gradient of 10,000 volts/cm.

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Radiative energy in present day microwave systems is generated, not at the antenna surface, but in a separate unit, from which it is piped to the antenna. The whole design is governed by the technology of present day energy sources. To exploit that technology to the limit is certainly an approach that deserves strong support. However, it may also be worthwhile to ask whether quite a different design can be conceived, in which the energy source and the antennas are one and the same piece of equipment. Components for pulsing or modulating the outgoing energy are already eliminated because it is energy transmission that is desired, not information transmission as for radar. It is, therefore, tempting to try to eliminate other components as well, such as magnetron and piping to the antenna. A model system offers itself as inspiration in the search for conceptual simplicity: the atom. A single electron circulating about a nucleus serves as both power source and antenna.

Any attempt to conceive of an energy source spread over the antenna itself has the following guide lines:

- a. A distribution of current over the surface at a uniform density of the order of 1 to 10 amperes per cm, or a more patchy distribution with higher local densities.
- b. Potential gradients of the order of 10,000 volts per cm on the average - again with non-uniform distribution a possibility.
- c. Periodic variation of the currents, properly synchronized in both space and time.
- d. An energy input.

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Appendix "A"
IDA-ARPA S-1

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In other respects there is an enormous range of freedom for conceptual design. The following possibilities are among the many that obviously come to mind, individually and in combination:

- a. A high current electron or proton beam.
- b. Deflection by electric and magnetic fields.
- c. Plasmas and plasma vibrations.
- d. Arcs.
- e. Cavities in electrical oscillation.
- f. Direct powering of the antenna by contact with rapidly rotating parts, such as magnets or cavities, driven by turbine or otherwise from a primary thermal energy source.
- g. A plasma driven by a controlled thermonuclear reaction.
- h. A receptor identical in design with the emitter.

To have seen emerge in only two decades the magnetron, the klystron and a variety of traveling wave tubes is to recognize that the opportunities for invention are limitless. However, it is not clear that the incentives for invention of a new energy transmission source, and some of the requirements for it, have ever been explicitly formulated and put before those with the greatest creative imagination and proven inventive ability in the field of electronics. J. R. Pierce, in an appraisal of the possibilities for generating electromagnetic energy, states, "Progress along such novel lines can only come if exceptionally gifted physicists and engineers can be interested in thinking hard about such matters." It would appear worthwhile to convene an expert

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work-study group under conditions optimal for generating new ideas in this area of transmission of energy by centimeter waves. Some members of Project Sherwood would undoubtedly have a special contribution to make. The view has often been expressed that this intensive work on thermonuclear energy may in the end contribute even more through an understanding of the science and engineering of plasmas than through achievement of an important new energy source.

At still shorter wave lengths, still more imaginative methods suggest themselves for emitting energy. Among the possibilities now under consideration in a most modest way are:

- a. An electron beam guided at the proper distance above the surface of a ruled grating to produce visible radiation (W. W. Salisbury).
- b. Coherent emission of infrared radiation (Charles Townes and Benjamin Lax) as contrasted to the incoherent radiation from thermal sources.

The opportunities in these and other directions are so limitless that this field deserves intense support and stimulation.

The possibility also deserves consideration that an atomic bomb can be induced to emit radiation of a selected wave length, possibly even directed radiation, by etching the casing with a structure of cavities to stimulate hydrodynamic plasma vibrations, or with other special geometry.

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Gravitational Radiation and Neutrinos

These forms of radiation offer, in addition to electromagnetic waves, the only known methods to transmit energy through space with the speed of light. They are among the most interesting topics in modern physics. However, there is not the slightest evidence today that these forms of radiation warrant work looking towards specific applications.

Acoustic Radiation

The maximum steady state rate of transmission of energy will be of the order

(speed of sound) X (thermal energy density of air)
or a few kilowatts per cm². The exponential rate of attenuation is quite low at reasonable frequencies. However, reliable beaming through the open air for distances even as short as a mile is normally out of the question, due to refraction by temperature gradients and winds.

Vortices

F. G. WERNER and the writer have duplicated in the laboratory one of the several known types of fireball. A glowing sphere, several inches in diameter, was caused to appear in the air and to move horizontally a number of feet, at a speed of a few meters per second, until it went out with a pop. A smoke ring generator had been filled with city gas and tapped to eject an invisible ring of gas. The ring, after traveling about a foot, passed through a spark discharge which ignited

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it. The glowing vortex continued to propagate. Presumably, mixing of gas with air took place until an explosive composition was reached and the fireball ended.

A large invisible vortex of explosive gas could be used to discomfit an enemy under suitable conditions, and might even be designed to produce heavy damage. The ring would travel noiselessly through space until ignited by flame or spark among the recipients or their equipment. The ring generator is of exceedingly simple construction: a box with a hole in one face and a rubber sheet for the opposite face. The vortex propagates through space with good preservation of identity, as seen in the behavior of "dust devils" above western deserts. However, the same observations show how very subject the aim would be to changes in wind direction and wind velocity. For this reason, repeated tries might be necessary to score an explosion. There are easier ways to cause trouble except under special circumstances, such as operations where stealth and mystery are required.

Vortices can also be propagated under water, quietly and invisibly, but strong enough - as one individual has testified - to knock over an unsuspecting bather. Applications are now known but might be conceived, such as carrying limited packages of energy, of poison, or of fuel, for limited distances.

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Beams of Particles

High energy electrons and photons are rapidly degraded in the atmosphere, losing about half their energy roughly every 1,000 feet. For high energy protons, the half-absorption distance is not much greater. This experience derives from cosmic ray and accelerator experiments where the stream of particles is too low in intensity significantly to affect the properties of the atmosphere which blocks the passage.

Lightning illustrates that currents can flow with sufficient intensity to affect the properties of the atmosphere itself along a narrow channel. This channel is very tortuous in the case of lightning because the first electrons to go that way had low energy, were easily scattered, and were often replaced by other electrons.

To replace these "uneducated" electrons by "educated" electrons from an accelerator might conceivably lead to quite new effects. If by use of high speed particles the channel can be made straight in the beginning, and the gas within heated so hot that the bulk of the impeding mass is driven aside, then the door is open to sending a quick burst of energy to a great distance. The use of such a burst to destroy a ballistic missile has already been proposed by one of the group, P. G. Kruger, and also by others. Absorption by the atmosphere has been the great difficulty in earlier thinking along such lines. A new look at the problem, allowing for the response of the atmosphere to the beam, is

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now very much in order. For this purpose, conceptual analysis and calculation, plus the enormous storehouse of existing information and theory about lightning, offer promising foundations for a much better assessment than we have today.

Specific Recommendations

a. Some agency should survey the present status of the field of propagation of energy through space to formulate:

- (1) The methods of energy transmission that have been considered to date by workers in this country and abroad.
- (2) The research now in progress bearing on the problem.
- (3) Research workers who can contribute imaginative and sound ideas or even more directly forward a future program in this field.
- (4) Specific applications of interest to the Department of Defense.

b. Starting from the state of knowledge as thus defined, a conference with a work-study character should be called - perhaps divided for some of the time into specialized groups - to generate new ideas, and to arrive at a first assessment of the areas most promising for future work.

c. Based upon the results of the survey, a steering committee of independent working investigators might be appointed upon the Project Sherwood model to:

- (1) Make recommendations to the sponsoring agency for research within existing government laboratories and for contracts to universities and research foundations;

- 52 -
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Appendix "A"
IDA-ARPA S-1

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(2) To call periodic conferences for review of ideas and experiments; and

(3) To bring to the attention of the Department of Defense areas where important applications can be pushed through.

As such leads develop, a more concerted effort should be made to bring them into practical application by agencies yet to be defined.

John A. Wheeler

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A-5. ATOMIC COLLISION CROSS SECTIONS

Knowledge of the interactions of electrons and ions with atoms and molecules has important applications to the defense effort, as well as to many branches of science. We may mention a few such applications:

a. Atmospheric physical ionospheric ionization and recombination rates; this is of importance for some proposed methods of interfering with enemy communications and radar;

b. Weapons physics (ARGUS is one of the many important applications);

c. Missile development (the re-entry problem has been tied to several atomic reactions; the detection of missiles within the atmosphere may be closely connected with atmospheric ionization in the wake; means for destroying an ICBM within the atmosphere may exploit the weapons capabilities to such a limit that very detailed knowledge of atomic reaction cross sections becomes significant);

d. Plasma physics and magnetohydrodynamics;

e. Controlled thermonuclear reactions - here lack of knowledge of atomic and molecular cross sections involving impurities has been a serious problem;

f. Chemical reactions in gases.

Unavailability of accurate knowledge of atomic cross sections has retarded development in each of these fields.

Although the basic information has been available for 40 years, much of atomic physics has been by-passed in the course of the development of physics.

This is true, particularly, of the study of the cross sections for scattering electrons and ions by atoms and molecules. It seems apparent that there do not exist "rules of thumb," or any practical theoretical basis, for making even qualitative predictions as to how these cross sections depend on the details of atomic structure. Also, no comprehensive handbook tabulations of cross sections exist.

There has been little improvement in theoretical techniques for handling these problems since the late 1930's. Developments in intense ion sources and atomic beam apparatus will provide new experimental techniques which are just beginning to be used.

Most work in this connection has tended to be fragmented. An individual worker determines the cross section for an individual reaction. Such results do not in themselves secure a systematic description of the phenomena. Also, much of the work has been quite inaccurate, discrepancies as large as a factor of ten remaining even after extensive studies have been made.

Recommendation:

A specific program for the study of atomic collisions might involve:

a. A survey and coordination of existing work (for example, by sponsoring conferences);

b. Support of atomic beam and other experimental apparatus to develop practical means of measurement;

c. Encouragement of a supporting theoretical program to use new techniques in quantum mechanical scattering theory and computing methods;

d. Emphasizing the importance of relating observation to the details of atomic and molecular structure -- and thus to obtain means of predicting cross sections from a knowledge of atomic structure;

e. Preparation of a systematic tabulation of cross sections, as has been done, for example, by the Hughes Committee on nuclear cross sections

K. Watson

A-6. MATTER UNDER EXCEEDINGLY HIGH PRESSURE

Recent investigations by E. G. Drickamer and co-workers have disclosed that substances under very high pressures (of the order of several hundred thousand atmospheres) exhibit unusual properties. Heretofore most of the very high pressure work has been concerned with investigating the effects of compression as seen after release of the pressure. In contrast to such studies, Professor Drickamer has succeeded in measuring certain physical properties (such as infrared absorption

and some electrical characteristics) while the substance of interest was under extreme pressure. Among other things, he found that non-metals begin to show some metallic characteristics when the atoms are squeezed together so closely that nonbonded electrons from different atoms begin to interfere with each other.

It is now suggested that the measurement of properties of materials under extremely high pressures warrants further intensive study. Such study might enable us to understand better some of the phenomena occurring in nuclear explosions. It is also conceivable that a whole new realm of solid state physics and physical chemistry might be disclosed. It is quite possible that the results would be of substantial value to astronomers. Finally it is suggested that compounds of excited helium with other elements might be made under high pressures. If stabilization of such compounds could be discovered, a new type of fuel might result.

Recommendation:

Support by an appropriate agency for good and forward-looking research proposals.

F. T. Wall

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A-7. INTENSE MAGNETIC FIELDS

In the recent past it has become possible to achieve very intense magnetic fields, $\geq 10^6$ gauss. The eventual scientific and technical implications of very strong fields are not now clear but their importance is already evident. The essential point is that an entirely new range of physical parameters has become accessible: magnetic fields with an energy density approximation high explosive have already been produced with an expectation of even higher fields. The characteristic of matter under the action of such fields should be studied from the fundamental point of view, as should the fields themselves.

A few examples of promising uses include: (1) the study of mixing in implosive systems with the field as the light-decelerating medium; (2) the acceleration of charged particles by the action of the magnetic field; (3) construction of tiny focusing magnetic systems for use with pulsed high energy machines; (4) inhibition of the photographic process by the action of strong magnetic fields; (5) containment of a plasma by longitudinal as opposed to pinch-type fields.

Some ideas have been advanced as to ways in which even more intense pulsed fields can be obtained by means of nuclear explosions.

To date the amount of work done in this subject in the free world is very small, with only a few active workers. Evidence exists that the Russians are active in this field.

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Recommendation:

An appropriate agency should sponsor a symposium on intense magnetic fields and seek for means to stimulate more forward-looking work in this field. Among those active in the field who might be invited to help organize such a symposium are:

H. P. Furth (Livermore)
C. M. Fowler (Los Alamos)

F. Reines

A-8. FORMATION OF CONCEPTS OUT OF DATA; AND SYSTEMS RELIABILITY

The Problem

One of the principal problems that frequently arose in the course of Project 137 has been connected with large-scale data handling. This includes identification, classification and evaluation, in addition to computations proper. Problems of this kind are common to all three services; in addition, there is the problem of information flow within the government itself. Justifiably the three services have individually pursued many avenues of solution for their many problems, right down to the fundamental aspects. These problems are, however, parts of a much more general picture. It is therefore useful to learn more about the basic underlying structure of this picture.

The New Approach

It is well recognized that computer development has been most impressive and that ambitious plans for very fast computers have

Appendix "A"
IDA-ARPA S-1

- 59 -
~~SECRET~~

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been formulated. However, it is our conviction that other, qualitatively different considerations should now be sought. When information about a prevailing state of affairs is collected and stored, this is done for the purpose of answering questions and making decisions. Hence, entirely novel procedures of automatic data management must be developed which permit rapid sifting and assaying of individual items of information as to their relevance in generally complicated contexts, possibly appreciated only in a qualitative way. This operation of "intelligent" recognition of significant items in a massive volume of a priori undifferentiated (background) information is in marked contrast to the familiar approach by exact, abstract relations and precise item-by-item sorting. Important contributions toward this end will undoubtedly come from a deeper understanding of how computers can better interact with neurological phenomena. As is well known, the function of decision-making involves data processing and computations combined with thought processes.

The exceedingly high speed of computers contrasts with a much greater flexibility of the human mind. For example, in directing air defense, computers have been known to arrive at correct solutions -- but at the price of very many changes of orders during the simulated battle. Human operators have been able to achieve the same kill probability with fewer changes. A problem is, therefore, how to combine the speed of the former with the intuitive power of the latter -- thereby attaining a higher level than either one can reach at present.

- 60 -
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Appendix "A"
IDA-ARPA S-1

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A generalized data processing system that attempts to incorporate the necessary, subtle features with heterogeneous interactions is likely to be a rather complicated affair. Its complexity exceeds that of the modern computers and data processors. But for such complex equipment, as for the recently proposed weapons systems, the question of reliability of performance naturally arises. Procedures for the systematic reduction of the probability of malfunction on the part of a given system constitute an immediate objective of great importance. Even more challenging, however, is the objective of devising our systems in such a way that any failure will subsequently affect only the lowest priority functions. Since it is patently impossible to build systems which never fail, the next best thing to achieve is the design of systems which do not fail when it matters. While it is true that logical design has attempted to keep pace with component development, the study of reliability and its attainment even with unreliable components has only been started. It is clear that this subject demands great attention in the present context. Especially is this true for systems operating under great constraints or in times of national emergency.

Familiar examples illustrate these remarks about (1) automatized formation of tentative concepts or conclusions; (2) quick sifting of masses of data to confirm or contradict these tentative conclusions; (3) design for reliability with unreliable components. In science, weather forecasting has progressed some direction along lines (1) and (2), but has far to go in systematic application of these principles.

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Appendix "A"
IDA-ARPA S-1

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In national defense, the fields of communication and intelligence offer outstanding illustrations. In these areas a well worked out philosophy of reliability and concept formation would greatly strengthen our position. Also, improvements would result in the behavior and reliability of a future anti-missile system or of the already-programmed POLARIS system, to take examples from a vast collection in the field of weapons. Finally, a deeper understanding of features (1), (2) and (3) of decision-making would allow more realistic and far more complicated versions of war games than those presently being carried out on computers.

Information Systems

Digital processing and decision elements, perfected in the rapid evolution of computers, are finding their way into modern military information and control systems in ever greater number and increasing sophistication. Yet, no matter how generalized for the purposes on hand, the pattern of procedures according to which they have operated to date is that of arithmetic: exact, explicit and complete like an accountant's books. In contrast, one needs to examine the principles of large memories, initially chaotic and with quite imperfect access, whose organization is effected and dictated by the application at hand. Systems must be thought of that "fan out" into many channels, and this at several levels, operating simultaneously. At succeeding stages, more and more detail may be accommodated, in a manner consistent with increased parallelism of operation. Further, an hierarchy of many

Appendix "A"
IDA-ARPA S-1

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subsystems of storage is desirable. These subsystems may incorporate various existing components like magnetic cores and tapes; electrostatic devices, both digitalized and analogue; electromechanical or photographic techniques; display scopes. There are other possibilities that have recently been proposed. What seems clear is that the conventional devices are either bulky, time-consuming, relatively inflexible, or impractical.

Rapid access to stored information is presently limited to small portions of the data. Scanning large amounts of stored data is usually a time-consuming affair. Subtle, imaginative schemes are needed here that represent new dimensions. Perhaps the physiologist and neurologist, in concert with others with different disciplines, can make radically new suggestions.

Such systems should be designed to provide flexible interaction with the human being. This is an important aspect. Heretofore automation has been applied under those circumstances which have been sufficiently simple to permit complete automation without human intervention. In fact, the exclusion of the latter has been one of the principal objectives. For the more subtle considerations envisioned here, the brain must be an essential component, interacting directly with the rest of the system, in a flexible fashion.

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Reliability of Systems

Quite apart from the questions of logical design and organization of a large system, there arises the separate question of the reliability of performance. The question is, of course, of serious interest to those concerned with any form of large system. Fundamental considerations have only been hinted at. What are the general criteria for evaluating the performance; to what extent can unreliable components be used; how much redundancy should be included; what forms of checking or corroboration should be incorporated; these are non-trivial questions. These problems are also closely related to the coding schemes used. While we possess a very powerful theory of information we still have to make a decisive step forward in order to exploit this theory fully; this step is in the direction of the discovery of systematic encoding schemes.

Some Immediate Tasks

With current, digital computer design furnishing an important take-off point for the proposed studies, a number of specific ideas in this particular field are suggested as warranting immediate exploration.

a. The present thinking restricts itself to a very small number, usually one or two, of arithmetic units per computer. The emphasis has, in large part, been on speed. However, with the development of cryogenic elements that lend themselves to printing techniques, it is

Appendix "A"
IDA-ARPA S-1

- 64 -
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possible, as first suggested by J. Pasta, to conceive of a computer with a fairly large number of arithmetical units, say a few hundred, if not a few thousand. Such capabilities must alter our traditional approaches to solutions of numerical problems, especially in the field of partial differential equations.

b. For many applications of Monte Carlo-type problems, the structure of arithmetical units is not very efficient. In most applications 10 to 12 bits per number usually suffice. The 20 to 30 bits that are usually available are quite unnecessary.

c. Faster and more complex computers are being designed to extend the range of tractable problems. For none of the computers being commercially produced has the question been raised of the significance, i.e., number of meaningful bits, in the answer or answers. One may imagine that an acceptable procedure might be to describe a number, not only as a fraction and an associated exponent, but with an "index of significance". This brute force approach clearly involves more hardware and control complications, if not some sacrifice in speed. Even so, it is not completely clear what the appropriate rules should be. Some suggestions have already been made, but more study is necessary.

General Recommendation

It is strongly recommended that a group be formed to study these problems and work out a basically new attack on them. It is necessary that the group include not only mathematicians and engineers, but

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Appendix "A"
IDA-ARPA S-1

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biologists, neurologists, logicians and physicists. This group must have at its disposal, free of encumbrances, funds and laboratory facilities; the detailed nature of the latter can be specified by the group as its ideas gradually develop. As these ideas become firm, it will be necessary to expand the program in some manner in order to reach its objectives of a working system.

The quality of people, together with the desired spectrum of disciplines, is suggested by the following list (apart from the study group). We feel that many of them could be interested in a program suggested by the present report.

Engineers: Julian Bigelow, IAS, Princeton University

Ralph E. Meagher, University of Illinois

Jerome Wiesner, Massachusetts Institute of Technology

Logicians: Claude Shannon, Massachusetts Institute of Technology

R. L. Ashenurst, University of Chicago

Minsky (cf. Shannon)

Mathematicians:

A. H. Taub, University of Illinois

S. M. Ulam, Los Alamos

H. Bremermann, Berkeley

Statistician-Systems:

J. W. Tukey, Princeton University

T. M. Anderson, Columbia University

Carl Ohman, National Science Academy

66
~~SECRET~~

Appendix "A"
IDA-ARPA S-1

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A. Newell, Carnegie Tech
W. W. Bledsoe, Sandia Corporation
Symonds, Standard Oil of New Jersey
H. Simon, Carnegie Tech

Physicists:

R. D. Richtmyer, New York University
Hugh Everett, Weapons Systems Evaluation Group
L. W. Alvarez, Berkeley
A. W. Lawson, University of Chicago
F. Seitz, University of Illinois
J. Bardeen, University of Illinois
J. Pasta, Atomic Energy Commission
A. Nordsieck, University of Illinois

Biological Scientists:

D. McK. Rioch, IAS, Princeton
A. Novick, University of Chicago
J. Hoffman, Buffalo
Joshua Lederberg, University of Wisconsin
J. Lettvine, Mass. Institute of Technology, RLE
F. Rosenblatt, Cornell Aeronautical Laboratory
H. Quastlee, Brookhaven National Laboratory

Specific Recommendations

a. An appropriate agency should sponsor an interdisciplinary meeting in the near future on Formation of Concepts out of Data and Systems Reliability, to study specific needs of this program, and to

Appendix "A"
IDA-ARPA S-1

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try further to appraise the prospects it will open out. Such a meeting could be held in the area of the Argonne - University of Chicago - University of Illinois complex.

b. An advisory committee should be selected from those actively interested in this field, to recommend appropriate practical means for forwarding new advances in the subject, including contracts and such new computation laboratory facility as seems appropriate.

c. Possibilities for application to urgent defense problems should be sought regularly and imaginatively through this advisory committee or otherwise, and, when identified, should be referred to appropriate agencies of the Department of Defense for the earliest possible development.

N. Metropolis
O. Morgenstern
F. T. Wall
F. J. Weyl

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A-9. ARPA AND THE SOCIAL SCIENCES

Although the considerations of this group have been largely directed to the bearing of the physical sciences on problems of Military Science defense, we have been much impressed by the possibilities offered by an imaginative exploitation of the social sciences in the same connection. A number of groups have addressed themselves to this matter, in an endeavor to identify areas of research which might hold promise in defense applications. Here we may cite in particular the work of the Subcommittee on Social Sciences of the National Academy of Sciences, and of the Ad Hoc Advisory Group on Psychology and Social Sciences, Office of the Assistant Secretary of Defense for Research and Engineering. Both of these groups have described broad fields of study which have obvious and important military applications of both immediate and long-range character. From both reports, one gathers the impression that far too little emphasis is being given to the exploitation of the powerful tools and techniques at the command of the social scientist.

Quite evidently, the present group, composed as it is largely of physical scientists, cannot presume to judge the merits of detailed proposals for work in the social sciences. Nevertheless, we cannot refrain from expressing our deep conviction that a vigorous exploration of these broader fields is of crucial importance to the defense of our country and that the advantages to be gained by their

exploitation may far outweigh those to be anticipated by the more mundane prosecution of hardware developments. The most sophisticated weapons system is of little avail if it is applied at the wrong place or at the wrong time or by the wrong people. More than anything else, we need imaginative formulation of policy, careful articulation of objectives, and considered evaluation of the relations of men, weapons, and missions. These are problems which can only be solved by an enlightened and aggressive attack, utilizing the full power of all the sciences, but with strong emphasis on the methodology and substance of the social sciences.

Recommendation:

We strongly recommend that every impetus be given to the fullest possible exploitation of social science and social scientists in all aspects of defense problems. More specifically, we urge that ARPA consider these fields an integral part of "Advanced Defense Research" and select for support and exploitation certain of the fields recommended as particularly important by the two committees previously mentioned. Persons who might be helpful in this field include:

Dr. Rensis Likert - University of Michigan

Dr. Dael Wolfe (Psychologist) - Executive Secretary - American Association for the Advancement of Science

Dr. Paul Fitts (Psychology, Human Engineering) - University of Michigan, Chairman, Social Science Panel, SAB, Air Force

T. Lauritsen
R. Weiss

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A-10. MILITARY EXPLOITATION OF BASIC U.S./USSR DIFFERENCES

One of the more conspicuous aspects of current U.S. defense planning is its close dependence on technological development. Surely it is vital to our security that we exploit to the fullest such possibilities as an improved mastery of nature can offer to increase our defensive and offensive capability. On the other hand, experience indicates that one way or another, every major advance of this character is promptly taken up by the enemy, with the result that the war-making potential of all countries rises with monotonous and frightening regularity, modified by only temporary fluctuations in favor of one side or the other.

For purposes of argument, we suggest that in the present state of culture of the nations immediately involved, the seeds of war lie in certain differences between nations, cultures and individual people. It seems quite unlikely that any serious conflict could arise if Russians and Americans were indistinguishable from the point of view of ideology, environment, standard of living, etc. If these differences could be made to disappear, there would be little occasion for war as long as the earth can feed us all.

If one agrees that the problem which confronts us depends upon a difference between the parties, it behooves us to exploit that difference in solving the problem. Only in this way can we hope to obtain an advantage which will be absolute, in the sense that

Appendix "A"
IDA-ARPA S-1

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duplication of the system on the other side will not constitute a counter. As an obvious but illustrative example, a weapon which incapacitated or destroyed any person who threatened to enslave his neighbor would satisfy most Americans and would be far more satisfactory to us than more conventional weapons whose discriminatory power depends on the accident of possession. Less trivial is the possibility that qualitative differences in the capability of independent thought and action by individual Russian and American soldiers might be exploited to our advantage, particularly in a war involving great dispersion of combat units. Not less important as a distinguishing feature, but less easy to exploit in our favor is the disregard for human life which seems sometimes to characterize Russian operations.

Quite evidently, the invention of a truly discriminatory weapons system is a difficult job. On the other hand, putting a man on the moon is also difficult, and the solution is far less interesting in the present context. We suggest that the relative allocation of effort to these two endeavors is lamentably disproportionate in view of their respective importance to the preservation of our society. Even a modest improvement in our understanding of the enemy may have the most important consequences for war and peace, and even the revelation of a single non-counterable weapon, diplomatic, economic, or military, may give us advantages far out of proportion to the cost of even quite an intensive study program.

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Appendix "A"
IDA-ARPA S-1

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To elaborate the matter somewhat, and to form some vague basis for a closer study, we examine here a few of the obvious points which might be considered - and might, of course, be much amplified. These remarks are directed specifically to the question: "What differences exist between the USSR and the U.S., and how can these differences be exploited to our advantage?"

a. Environment

(1) Russia is, to a considerable extent, a landlocked nation: communication by water is largely restricted to her canal and river system. Transportation of materiel and manpower from one point to another must therefore be relatively expensive, both in terms of capital equipment and fuel. To what extent can this expense be aggravated by wartime interdiction of the canals? Do the canals and locks offer any specially advantageous targets? Could the threat of amphibious operations on the northern coastline be used to force the Russians to maintain large forces in this inhospitable terrain? The rather conspicuous difference in the availability and usefulness of the oceans to the two sides would suggest that strong emphasis on naval and amphibious capability on the part of the U. S. might well be to our advantage. This is clearly an example where we need not, and in fact must not, simply attempt to match the Russians one to one. In the past, command of the oceans has many times determined the fate of nations.

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(2) Eastern and Western Russia are rather poorly connected: important installations on the Pacific are separated by vast reaches from the center of authority. Might it not be possible to cut off and eliminate essentially all of Siberia with a relatively small effort? Would it be possible and profitable to establish and supply large bases of our own in this territory?

(3) Large areas of Russia have extremely cold winters and offer only marginal support for their populations. Could this situation be aggravated by any conceivable modification in climatic or ocean current patterns? What would be the consequences of a moon shot? Would cutting the Isthmus of Panama affect the Gulf Stream? What are the possibilities of modifying rainfall patterns by systematic cloud seeding in Western Europe? Could a new Ice Age be induced in Northern Russia?

(4) Prevailing winds in the Northern Hemisphere run from West to East. Can this factor be exploited through massive gas or fallout attacks? Could the mere threat force Russia into expensive countermeasures? Could balloon-carried weapons or instruments be used to our advantage? What use can be made of the jet stream?

It is abundantly evident that many more differences can be discovered in the environment, social structure, economics, and personal attributes of Russians and Americans. Opinions will differ as to

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which of these differences can be turned to our advantage in a military sense, but an adequate appreciation of their existence and of their implications is surely essential to the most rudimentary approach to the basic problem. It is suggested that a systematic study by a group comprising experts in both social and physical sciences might reveal possibilities for some quite sophisticated weapons.

Recommendation:

Support of such a work-study group by an appropriate agency.

T. Lauritsen

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B. ENVIRONMENTAL ANALYSES

B-1. THE PHYSICAL ENVIRONMENT OF MILITARY OPERATIONS

Of the many factors which bear on the effectiveness of weapons systems of any kind, surely a broad knowledge of the physical environment in which they are to function is among the most basic. Whatever our weapons may be, they must operate in the land, sea, air or the space outside, and in many cases their design must make explicit use of the properties of these media, particularly those properties generally categorized under the fields of geophysics, oceanography, meteorology, and physics of the exosphere. Because of their great importance and universal interest, all of these subjects have been explored in some detail, both by military and civilian investigators, and an extensive body of knowledge has been accumulated. Within each of the individual disciplines, many national and international agencies have been established to coordinate research activities and to facilitate collection and dissemination of information. In addition, the individual military services have vigorously supported both basic and applied research in these fields to the extent that one may say that there are no immediately obvious subjects of military importance in which effort is completely lacking.

On the other hand, ARPA has a responsibility which transcends the obligations of any individual military arm, and one which is not necessarily met by any purely civilian agency. ARPA should concern itself with long-range projects, often out of the context of a

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Appendix "B"
IDA-ARPA S-1

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particular application, and should be prepared to exploit any improvement in basic knowledge, particularly in the fields under discussion here.

Under these circumstances, it would seem appropriate to suggest that ARPA maintain an active interest in these fields of endeavor, and search actively for subjects of possible military interest in which it may be desirable to increase the level of support.

In the Work-Study Group's brief exposure to current military problems, several fields have appeared which seem to deserve increased attention. Of these, perhaps the most conspicuous are those branches of oceanography and "ocean meteorology" having to do with long-range sound transmission, propagation of electromagnetic radiation in water, and the topography of the ocean floor. It seems that U. S. effort in these matters is on a far smaller scale than that of the USSR, particularly on the last-mentioned subject, and far less than their importance would justify.

Another field in which more effort would seem to be indicated has to do with the effects of radioactivity from nuclear weapons in the environment of a ground army. There seems to be insufficient effort in this area relative to the importance of a thorough understanding of this matter and of the tactical advantages to be gained from an ability

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to deal with it. ^{1/} Aside from the rather obvious observation that the necessary instruments and indoctrination do not appear to be available on anything like a realistic basis either in the Army or among the civilian population, there seem to be significant gaps in the basic knowledge required to deal with fallout problems.

Still another area where a hard look is required to determine whether our current research effort is adequate, concerns the properties of the upper atmosphere, the ionosphere, and outer space, especially as regards propagation of electromagnetic radiation and charged particles. It has become apparent that the feasibility of a number of weapons systems under current discussion depends in a direct way on certain of these properties about which only guesses can be made at present.

It should, perhaps, be observed that the functions of the U. S. committee on the I.G.Y. are illustrative of the power and usefulness of a coordinating agency in accelerating a broad field of study. With a budget and a manpower commitment which is certainly not excessive, this group has enlisted active support from a large number of independent institutions and have done much to make possible research on a world-wide scale.

^{1/} It should be emphasized that the Study-Group's information is quite scanty and that the implied criticism may be quite unjustified. These remarks are intended only to suggest that the situation be examined.

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Recommendation:

The possibility that ARPA might perform a similar service, or even inherit certain of the functions of the I.G.Y. committee would seem worthy of serious consideration.

T. Lauritsen

R. Shephard

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B-2. RADIOLOGICAL MAPPING AND COMBAT SURVEILLANCE

Currently planned nuclear explosion detection and analysis techniques seem, on the whole, to fill a significant part of the need for combat intelligence on this subject. On the other hand, the proposed system is rather complex and much of the information obtained is of less than immediate interest to local Battle Group and Divisional commanders. For the purpose of an officer planning an immediate operation in a battle area where nuclear weapons have been used, the principal questions must evidently have to do with the existing radiological situation within the locality in which he expects to maneuver. For him the greatest need is for a current, detailed radiological map and for the ability to make quick spot checks at points within a few thousand yards of his lines.

The levels of radiation which are of military significance are enormously high compared to those which are encountered, for example, in mineral prospecting. Typical levels in the latter case would be some tenths of milliroentgens per hour, whereas a level of some tens of roentgens per hour might well be regarded as an acceptable risk for transit of troops. It follows that the necessary instrumentation for military applications can be most crude and rugged - possibly designed along the lines of a meteorological radio-sonde.

A number of obvious solutions suggest themselves, ranging from the most simple, expendable instruments, available even at platoon

Appendix "B"
IDA-ARPA S-1

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or company level, to drone-carried or rocket- or mortar-fired devices, controlled, for example, at divisional or corps level. As a minimum, it would appear that daily weather maps issued by local meteorological units could easily include rather detailed radiological information. In addition, as indicated above, quite simple arrangements would permit a local commander to investigate the situation for himself at any time.

The matter dealt with here does not in itself require any basic study, nor indeed any appreciable development. On the other hand, the apparent lack of emphasis on this problem in current planning for combat surveillance measures suggests that the implications of a radioactively-contaminated battlefield as a matter of daily course may not have been incorporated into operational doctrine to the extent which the situation demands. The existence of high radiation levels as a more or less permanent feature of the environment poses a number of questions, and the ability to accommodate to such a situation may well be decisive in an operation involving nuclear weapons.

Recommendation:

Emphasis in current planning on radiological mapping and combat surveillance.

T. Lauritsen

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B-3. STATISTICAL DATA TO PLAN FALLOUT ASSOCIATED WITH
USE OF ATOMIC WEAPONS BY ARMY GROUND FORCES

How to lay down tomorrow a desired pattern of fallout is important for an area commander just as it is important for local commanders to know how to lead their troops safely through today's battlefield radioactivity.

The planning of ground bursts to achieve a desired fallout pattern is only partly understood. The planning depends on meteorology, plus such knowledge of the winds as is given by field measurements. Proper planning demands more - a knowledge of how reliably a specified fallout pattern can be secured.

Recommendation:

An appropriate agency should sponsor research:

- a. On the statistical variations of winds - in time, distance, and altitude - about the values indicated on the kind of measuring equipment that will be used in the field; and on the correlations among such variations;
- b. On the planning of measurements for this purpose; and
- c. On how to use the results to tell what one can do reliably about securing a desired fallout pattern.

R. Shephard

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B-4. A RADIATION DETECTOR FOR FIELD USE

The urgency of providing a simple and adequate radiation detector for field use has led to the development of a large variety of ingenious devices, and there seems little doubt that if the need becomes sufficiently acute, several quite satisfactory solutions will be available. The present note describes a scheme which offers some advantages as an interim measure and which might deserve some further study, at least to the extent of assuring patent protection of the government's interest.

Among the many devices which can detect nuclear radiations, probably the most familiar is the Geiger-Müller counter, which gives an electrical response in the form of a single pulse each time an ionizing particle traverses the sensitive volume. Under normal conditions, the cosmic rays and natural background radiations will produce a few counts per minute in a Geiger tube with a volume of a few cubic centimeters. For the most primitive device of this sort, four elements are required: a Geiger tube, a power supply of a few hundred volts, a simple amplifier, and an indicator - often in the form of a headphone or loud speaker. With the exception of the Geiger tube itself, all of these components also exist in any vacuum tube radio receiver. In principle then, conversion of a standard receiver to a radiation detector requires only the addition of the Geiger tube.

Appendix "B"
IDA-ARPA S-1

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Many possibilities for the mechanics of the conversion suggest themselves immediately. Perhaps the most attractive would appear to be a simple replacement of one of the audio amplifier tubes with a plug-in unit comprising an identical tube to which is attached the Geiger counter and associated electrical circuitry. The Geiger counter tube, which need be no more bulky than the standard miniature radio tube, might be connected from the amplifier tube's anode to the control grid, with a suitable coupling condenser and a limiting resistor, the whole arrangement mounted on a standard plug-in base so that no internal connections need be made. A slightly more sophisticated version might incorporate a separate switch to disconnect the Geiger tube when desired.

In normal operation, the effect of the Geiger circuit would be to superimpose occasional "clicks" - some 5 to 30 per minute, depending on the size of the detector - on the normal receiver signal, providing a constant monitoring of the background radiation whenever the receiver is in operation. Any significant increase in radiation level would immediately manifest itself by an increase in the frequency of clicks. An increase of a factor of two or three would call for some investigation - a factor of ten increase would be far outside the limit of normal fluctuations in background, and would constitute a definite warning. A factor of 100 would represent a radiation level in the general neighborhood of the so-called tolerance dose (a few tenths of a roentgen per week). A dangerous radiation level would produce a continuous series of clicks, or might even render the device inoperative

[REDACTED]

(this last contingency could be guarded against by suitable circuitry).

An ordinary radium-dial watch held close to the Geiger tube would evoke an immediate response and would provide a convenient method of checking the function.

It is evident that the Geiger counter device here conceived does not provide all the quantitative information which might be desired in case of a fallout attack either in military or civilian situations. Such information requires more sophisticated instruments and the interpretation requires trained observers. On the other hand, in the present world situation, and for the immediately foreseeable future, what is required is a warning device which is sufficiently insistent to command attention, and which will not be found to be out of order when the need comes. Assuming that the technical development does not present unforeseen difficulties, devices of the kind described here could be procured very rapidly and easily installed in the field. They could be made available for all military radios down to company level, and possibly even to platoon level. Conversion of civilian radios would be equally straightforward. Adaptation to low-voltage, battery-operated or transistor receivers can certainly be made, but would probably present some complications.

Recommendation:

Construction of plug-in inserts of maximum simplicity and evaluation with a view to widespread installation.

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- 35 -

T. Lauritsen

Appendix "B"
IDA-ARPA S-1

B-5. MILITARY GEOPHYSICS

Meteorology is an important input into the military equation and, by this token, is an important part of military geophysics. But, so also are climatology, geography, drainage, landforms and ecology. Much data in these areas must still be obtained. Also, much exists which has not been used or even comprehended. Military meteorology available at the time, if used, could have changed Napoleon's campaign in Russia; Hitler neglected to profit by Napoleon's lesson; and the same mistake was repeated in Korea by our own forces. In each case communications apparently broke down. The men just didn't get the word.

Today there is equally narrow understanding of the importance of military geophysics for future struggles. A detailed knowledge of rainfall, soil factors and the covering road net in future combat regions may be just as important in the solution of the mobility problem as a much-hoped-for breakthrough in drive power for vehicles. Systematic study of the local meteorology of the Korean combat zone, with forecasting techniques to predict whether or not the second valley over is fog-bound, or will be fog-bound in four hours, may well have changed the outcome of engagements as well as indicating entirely different tactics.

[REDACTED]

The following sorts of information will be urgently needed in future land combat. Mastery of techniques to get this information can well spell the difference between victory and defeat.

Indirect Bomb Damage Assessment

Knowledge of the optimum effectiveness of nuclear weapons in casualty production requires a knowledge of what the meteorological environment of the target area will be at time of strike. Atmospheric attenuation in the target area will have a marked effect on the effectiveness of thermal radiation as a casualty producer and, also, can aid in the estimate of how much protection can be afforded to exposed personnel.

Use of Photography, TV and Infrared

To be fully effective, the above techniques being planned for combat surveillance must take account of the effect of meteorological factors on atmospheric transmission of visible and infrared radiation. Absorption of infrared due to the presence of water vapor and carbon dioxide in the air, and the attendant scattering of the shorter visible wavelengths, seriously affect the performance of optical and infrared equipment, so much so in some cases as to make the equipment useless.

Meteorological Corrections for Sound-Ranging

Wind fields, water vapor content, and inhomogeneities in the atmosphere have a significant effect on the accuracy of bearings on

[REDACTED]

enemy artillery and weapons as determined by sound-ranging gear. Sound-in-air detection as a technique has been effective in World War I and II, but the limitation on accuracy of location of enemy weapons depends upon the ability to obtain timely meteorological data as well as to determine the influence of landforms and vegetation on acoustic ranging.

Meteorological Corrections for Ballistic Missiles

Unguided missiles, and, in a number of cases, missiles with terminal guidance, require knowledge about the wind fields to apply corrections for accuracy. In particular, such missiles as the LITTLE JOHN are affected by low-level winds during launch. Little is known about the variation of local winds and how to measure them to effectively correct the paths of such missiles.

Meteorological Data for Fall-out Prediction

Existence on the nuclear battlefield will depend upon being able to estimate height of burst, position and yield of the weapon, average particle size of radioactive material, velocity of fallout profiles, and wind fields as a function of altitude. Studies in these areas are far from adequate. Far greater effort must go into such studies before the answers to fallout prediction can be given.

Meteorological Corrections for Radar Accuracy

Radar range accuracies are limited today by the variations in the propagation characteristics of the atmosphere. Accurate knowledge of refraction is closely linked with the meteorology of the propagation

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medium. Further improvement of radar accuracy can be enhanced by more accurate knowledge of meteorological factors involved.

Meteorology for Army Air

Army Air although limited by size of aircraft, flight altitude and range requires the same type of meteorological inputs traditionally associated with the early growth of the aircraft industry. Much interest will lie in local meteorology rather than the synoptic type forecast now available. Landing fields will be rudimentary in construction; night operations will predominate, and various kinds of sensing equipment carried on board will be directly influenced by the atmospheric conditions. Without a full understanding of the factors influencing the environment, no local forecasts will be possible and the full potential of aircraft will be highly degraded.

General Meteorology

Much as been said regarding the importance of meteorology in weather modification, in climatology, in mastery of the Polar and tropical environments and in upper atmospheric phenomena. The attack on the problem of synthesis of the many related phenomena has been very spotty. There appears to be no central group concerned with an overall understanding of these phenomena and their relation to military and civilian requirements.

Recommendation:

The Department of Defense has a vital stake in meteorology and other fields of military geophysics. The present unsatisfactory state of military meteorology is a reflection of the retarded and narrow scope of unclassified meteorological research. An appropriate existing agency should consult with L. Berkner and others closely associated with advanced thinking in this field, to determine what should be done to produce an order of magnitude improvement in the present level of forward-looking research in this field, and in the amount of young talent attracted to it.

R. Weiss

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B-6. ON DETECTION OF SUBMARINES THROUGH SURFACE EFFECTS

Several suggestions have been made concerning the possibility of tracking submarines or surface vessels by virtue of changes which they produce in the water. These suggestions include detection of electric or electromagnetic fields, detection of induced radioactivity (for nuclear-powered vessels), chemical sensing, and bolometric measurements. It would seem natural to inquire whether the mechanical disturbances of the water does not deserve more consideration in this connection. It is well known that the wake of a surface vessel remains discernable to the naked eye for long periods - certainly many minutes, sometimes for several miles behind a fast-moving vessel. It may be presumed from this observation that some change which is introduced into the water by the propeller must persist in a form which may be detectable at even greater distances with suitably chosen instruments.

One conspicuous change which is associated with propeller action is the introduction of large quantities of rotation, in the form of "whorls", or cells of circulating fluid. Dissipation of the angular momentum of these cells occurs almost entirely through viscous forces, and in such a relatively non-viscous fluid as water, such cells may be expected to persist for a rather long time. An instrument designed to detect small amounts of rotation in the water might then offer the possibility of a specific indicator of propeller action, even long after the source has passed. Diffusion of the whorls to the surface might reveal the presence of even a deeply-submerged submarine.

We understand that some attention has been given to the detection of this and other surface effects by both Canadian and U. S. investigators, and that the results seem promising, although some aspects of the phenonema observed remain obscure. These reports, together with the puzzling observations referred to as Nidar, Chloe and others, suggest that we have much to learn about the mechanical properties of the sea. Quite recently, the ONR have undertaken a major program in an effort to identify the important areas for further work in this field. In view of the importance of the subject and the expectation of rapid advances as more effort is brought to bear, we recommend that ARPA keep abreast of these developments and be prepared to lend further support to the program if required.

T. Lauritsen

J. Weyl

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C. PROJECTS AND APPLICATIONS

C-1. BALLOON ATTACKS AND OTHER NON-CONVENTIONAL WEAPONS

In various current studies the possibility of using fallout in a retaliatory attack on Russia is considered. The fact that west-east winds prevail is of great importance in this connection, but our knowledge of these winds, their seasonal shifts, local peculiarities, etc., is inadequate.

It is necessary to point out that the possibility, envisaged by some, of using balloons, carrying nuclear weapons into Russia, encounters great difficulties. For one thing, they would have to be released in Western Europe and it may be difficult to accomplish this during wartime there. They may drift into friendly territory, etc. But they may offer some possibilities in a prolonged war.

It is quite different should Russia decide to use this method of attack and combine it with other forms of attack. Such balloons, carrying perhaps megaton weapons, could be released in Siberia, or by submarines in the Pacific, reach the jet-stream and drift over the whole of the U. S. and Canada. They could be fused so that they sense cities (by means of infrared), or other objects. They would carry self-destructive devices; e.g., so that they detonate at least over the Atlantic Ocean should they have failed to go off over the U. S. Balloons traveling at, say, 60-80,000 feet, would play havoc with our local air defense. They cannot be reached by fighters and are difficult to shoot down by expensive missiles. Many of them would be decoys, but it would

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be impossible to distinguish decoys from the real thing. Even if the balloon were shot down, the weapon could easily be fused so that it would explode at any rate, at any predetermined altitude, while falling to the ground. It is a cheap weapon.

It is true that all this would obtain were we to use balloons against Russia. What needs to be pointed out, however, is that we have here another instance of the fact that many technological developments of the last years give a greater advantage to the Russians than to ourselves, even if we should have initiated the development. It is clear, for example, that the density of our population settlements makes the U. S. far more susceptible to fallout attacks than Russia is. A POLARIS-type Russian submarine force is another case in point. The miniaturization of nuclear weapons opens the way for the Russians to use them in sabotage and other clandestine operations far more effectively than we can ever do in regard to them. Clandestine operations against SAC, for example, deserve the fullest study; the presently-taken precautions against them can easily be nullified.

The purpose of this note is mainly to indicate that we should not be exclusively concerned with the new features of future weapons systems. We should also try to solve the problems offered by the unconventional uses of existing weapons. It must not be forgotten that some decisive victories in past history, reaching far back into antiquity, were gained precisely because some imaginative leader thought of a surprising use of weapons which in no way differed from those of his enemy.

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Appendix "C"
IDA-ARPA 3-1

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A balloon attack on this country could, taken by itself, never be decisive. This is obvious. But with proper timing, and in combination with other forms of attack, it could produce enormous amounts of confusion, fear, and cause large damage. It is a particularly unpleasant weapon should the nuclear war tend to be prolonged. One recalls the Japanese balloon attacks which were only a nuisance; but much has happened since, and the whole matter has taken on entirely new dimensions. For that reason, much thought should be given to the non-conventional forms of warfare.

Recommendation:

Balloon attacks and other non-conventional forms of warfare should be quickly and most thoroughly explored with all the aid science can offer, through work-study groups composed of able, imaginative people, and through other effective means.

O. Morgenstern

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C-2. DEVELOPMENT OF BREEDER REACTORS

In response to various requests within the group, I note down herewith, in short form, my views on the development of breeder reactors in the U. S.

a. There is not enough U^{235} in the world to justify our enormous nuclear power program that would sustain the future world economy by burning U^{235} as a supplement to fossil fuels.

b. Utilization of resources demands that we learn how to burn effectively all of the raw materials - namely U^{233} and Th^{232} . Uranium and thorium must be thought of as complementary fuels in the same sense that coal and oil are complementary fuels.

c. The successful development of any breeder reactor to the point where it can be duplicated on a large scale for general use is a long and exceedingly difficult technological job. It will be necessary to expend substantial sums of money over many years to accomplish this aim, no matter when the program starts.

d. In the context of the over all importance to the future of the fuel problem (see Recommendation A-3), I do not believe we are devoting enough emphasis to the development of breeder reactors. Although some work has been continuing in this area, the nation's reactor development program does not have as one of its principal goals

Appendix "C"
IDA-ARPA S-1

- 6 -

~~SECRET~~

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the development of successful breeder systems based on both uranium and thorium.

Recommendation:

The importance of nuclear reactors for the long-term future of the fuel logistics problem (A-3) requires that a much greater effort be made to develop breeders based on both uranium and thorium.

R. Charpie

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C-3. UNDERSEA BEACONS

During our briefings considerable emphasis was given to the problems of generating high-power acoustic sources for long-range propagation and ranging studies. It appeared that a valuable contribution to these general problems might be made by the design of a high-power, unattended, undersea acoustic beacon, whose output might be programmed.

To this end the following observations are made:

a. Of the possible energy sources which suggest themselves, only storage cells and thermal energy from fission products have been considered. One cannot, at this time, select between them for lack of detailed knowledge covering the storage cell situation.

b. General Dynamics has done some experiments on producing acoustical energy in water with a spark gap source. They have been very successful according to information which has been received. It should be pointed out that apparently similar experiments at Woods Hole have not been very successful.

c. The U. S. is now producing enough Ce^{144} in the Hanford and Savannah River plant wastes to power several hundred such beacons per year according to preliminary calculations. The conceptual beacon design which has been considered has a useful lifetime of the order of a few years. Other possible fission product sources have not been studied, although there are undoubtedly other satisfactory raw materials.

- 33 -
~~SECRET~~

Appendix "C"
IDA-ARPA S-1

~~SECRET~~

d. Using Co^{144} as a heat source, and using the required number of copper-constantan thermocouple junctions, it is readily possible to produce a beacon which can charge adequate capacitance in parallel and, on command, switch the connections to series and discharge the stored energy into a spark.

e. On the basis of the General Dynamics experiments mentioned above, it appears possible to obtain the energy equivalent of 10-100 pounds of TNT with a repetition rate of the order of one pulse per hour.

f. The beacons can and must be designed to be self-destroying under certain predetermined situations.

Possible Uses

In addition to the uses of such a sound source for survey and research purposes, the following systems adaptations suggest themselves:

a. A peace-time aid to surface and sub-surface navigations. For example, a submarine may use the beacon for a secondary navigation system, and for the calibration of other undersea acoustical gear.

b. As a low capacity communication link between a deep-lying submarine and the continental U. S.

We advance these system applications only very tentatively.

Recent information communicated privately by Dr. Wiesner suggests that it is not a major problem to communicate to deep-lying subs from the U. S. (Also see "BASSOON", Appendix C-5). The reverse link

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from sub to U.S. is apparently still an unsolved problem. It is noted that there are in the Pacific and in certain areas in the Atlantic, SOFAR channels, by virtue of which a few pounds of TNT equivalent energy can be heard for thousands of miles. Accordingly, we conceive of an "I have heard you and will comply with instructions" signal being the principal requirement.

It is suggested that the submarine might communicate with the proposed beacon via a low intensity signal, and the triggered beacon communicate with the shore via a high intensity signal which the sub also hears; thus the sub knows that its acknowledgment of instructions has been transmitted.

Recommendations for Further Studies:

- a. Investigate the availability and capacity for production of Ce^{144} . (ONRL has been requested to investigate this matter now.)
- b. Investigate possible preliminary designs of a fission product-powered spark source. This is underway at ONRL.
- c. Investigate the utility of the underwater spark as an acoustic source. The General Dynamics and Woods Hole studies could be extended if a. and b. above suggest interest and feasibility.
- d. Investigate the extent to which POLARIS locations can communicate with the U.S. via SOFAR channels. Via Aubrey Price of the Navy, Woods Hole Laboratory has been requested to make an exploratory

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investigation of this matter. Preliminary reports indicate a favorable situation.

It is a relatively simple matter, once a design can be established, to build a battery-powered mockup of the proposed beacon and make some tests in the ocean. This would be a straight-forward and short-term experiment for any of the established laboratories.

If these ideas appear valuable to DOD and seem feasible, it is assumed that operational use would be determined by appropriate agencies.

R. Charpie

G. P. Kruger

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C-4. NAUCRATES DUCTOR^{2/}

Potential Purposes of the Weapon System

To provide a marine shield about U. S. continental shores, preventing penetration by enemy submarines to locations for delivery of IREM's on U. S. cities and military installations.

To provide a long range anti-submarine screen for U. S. Naval operations.

To sweep the oceans of all unfriendly submersibles and surface ships.

To attack unfriendly shore installations from great distances.

To serve as a vehicle for charting ocean floors.

Vehicle

A very high-speed hydrojet torpedo, powered by a small nuclear reactor. Speeds like 150 knots or greater are desired. The diameter of the torpedo need not be restricted to the usual 21 inches, because ejection from conventional submarine torpedo tubes is not essential. The nuclear reactor should be capable of operating for long periods of time. For dual capability for both reconnaissance and attack modes, it may be desirable to have a capability of assembling the reactor into a small nuclear explosion.

^{2/} Early thinking on this subject was given in a Sandia Corporation Technical Memorandum SCTM 285 58(51) (R. W. Shephard)

Appendix "C"
IDA-ARPA S-1

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Supporting Equipment

a. A homing sonar with large diameter transducer operating at low frequency, say 7 kc, capable of distinguishing submarines and other enemy submersibles.

b. A sensing device, if needed, with high power to distinguish submarines or other unfriendly submersibles from marine life and possible decoys.

c. A computer (or control system) to:

- (1) Execute homing and disengagement.
- (2) Respond to "don't home on me" coded signals from friendly vessels and submarines.
- (3) Make fusing decisions for attack mode.
- (4) Collect data and transmit messages for reconnaissance mode, and to execute required navigation for performing such transmission.
- (5) Execute navigation along predetermined sweep paths, or target approach paths when used against shore installations.
- (6) Respond to command control signals from control stations.

d. A navigation device to execute sweep paths or predetermined courses, except when interrupted by homing operations, with capability of resuming sweep when homing is disengaged.

e. Suitable transmitters and receivers.

f. Appropriate fusing and safing devices for attack mode.

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g. A suitable self-destruct device.

h. A generator, impelled by movement of the torpedo, and electricity storage for needed electric power.

Operation

The control of sweep paths and receipt of messages in the reconnaissance mode may be executed from shore bases or marine pickets, suitably located to provide a marine shield about U. S. continental shores or to intercept exit from unfriendly shore installations. Such locations may be widely separated, because the reactor hydrojet may presumably operate for long periods of time without service or replacements.

Before actual outbreak of hostilities it is probably essential to use the vehicle only in the reconnaissance mode. Here several alternatives are apparently available. Two of these alternatives are:

a. When a submarine is detected and homed upon, NAUCRATES may transmit a warning of the presence of the submarine and continue upon its sweep path.

b. Or, the reconnaissance torpedo may continue to tail the submarine with intermittent transmission of warning messages.

During periods of high risk, before hostilities, submarine approaches to our shores for delivery of IRBM's may be declared restricted ocean areas, and then the warhead option may be put into effect with U. S.

- 104 -

~~SECRET~~

Appendix "C"
IDA-ARPA S-1

~~SECRET~~

submarines protected by "don't home on me" signals. Shore-based and marine-stationed missiles and airborne weapons may be used, alternately, to make the attack.

The hazards of malfunction associated with the warhead option may be minimized by using the system in the reconnaissance modes during the early stages of development and operation. But it may be advisable, eventually, to introduce the warhead option.

The reconnaissance vehicle may be integrated with long-range listening operations, if the latter are effectively available. Then HAUCRATES may be sent over long distances from listening stations to suspected targets at speeds 5-10 times greater than other vessels or submarines (excepting hydrofoil surface craft), with capabilities of investigating potential submerged targets not available by aircraft or surface ships. Airlifting to search area may be performed, if needed. In either case, the search torpedo may be programmed or command signaled to return to base, if search fails to yield a target. If a target is located, it may be attacked by the search weapon, aircraft, or by shore or marine-based missiles.

Random movement about predetermined mean sweep paths may be efficient, and even unavoidable due to the existence of marine life not distinguishable as false targets in the early stages of a homing operation. If constant bearing navigation is used, the possible increased dispersion of the search torpedoes at the end of the sweep path

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will have to be accommodated by some dispersal of pickets and use of command signals. Inertial navigation, preprogrammed, may possibly be used, since the environment and response times required seem commensurate with existing or near future technology. Random movements may be superposed on the inertial navigation during the search operation.

An employment of NAUCRATES in regular, defensive shield-like reconnaissance sweep paths over long distances is probably desirable, but the exact patterns which may be most efficient need detailed study. Intermittent high-speed cruising and low-speed listening may and, perhaps, must be used to secure for the search torpedo a substantial radius of detection. Sonar search presents new problems at high speeds, particularly if the vehicle is traveling essentially in a bubble. If extensive enemy submarine action is clearly indicated, large numbers of search torpedoes, preferably with warhead option, may be used to sweep ocean approaches.

Naval task forces, including POLARIS-armed submarines, might obtain long-range defense against attacking anti-submarine submarines armed with missiles, by deployment of NAUCRATES in spiral search patterns, and by sending them against possible targets identified by long-range listening devices. In both cases it may be desirable to use the attack option of the reconnaissance vehicle. Also, NAUCRATES may be deployed to sweep mine fields, if the homing and sensing devices are adapted to this kind of attack.

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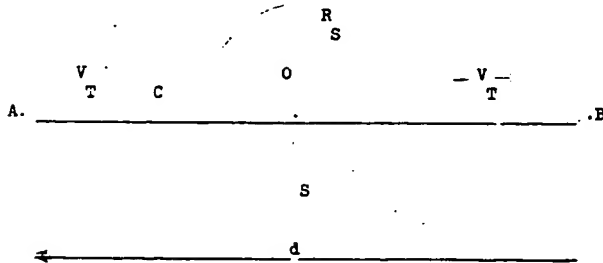
As a last thought: it may be possible to use such a reconnaissance torpedo to chart the ocean floors, if suitably instrumented and sufficiently accurate inertial devices are available to determine the exact location of sweep paths made.

Significant Parameters

A very rough calculation of system effectiveness will serve to indicate significant parameters and provide a simplified basis for judging the worth of the system.

Consider a sweep between two points, A and B, separated by a distance d , as indicated in Figure 1, and confine the calculation to a plane configuration.

Figure 1



Assume that the enemy submarine follows the strategy of crossing the sweep path at right angles with uniform velocity V_S . Let R_S denote the lock-on radius of the torpedo homing device; treat R_S as a sure

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number (i.e., not as a random variable) and assume kill is made if the submarine is caught within a distance R_S of the sweep torpedo.

The subset of points on the line AB for location of the torpedo where kill can be made is approximately the segment \overline{CO} ^{3/} where

$$\overline{CO} = \frac{2 R_S}{V_S} \cdot \frac{V_T}{V_S}$$

and the torpedo and submarine are taken to be moving in the direction indicated. This subset of points remains the same, if the direction of detection is restricted to the forward semi-circle.

Then, if, at the time the submarine starts to cross the sweep path at a distance R_S from the path, the positions of the torpedo on its sweep path are equi-likely, the survival probability of the submarine is approximately

$$1 - \frac{2 R_S}{d} \cdot \frac{V_T}{V_S}$$

² Exactly, to the segment \overline{CO} must be added a line segment to the right of O, starting at O and of length

$$x = R_S \left(\frac{V_T}{V_S} + 1 - \frac{V_T}{V_S} \right)$$

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For N such crossings, taken independently, the over-all kill probability

P_K approximately satisfies:

$$(1 - P_K) = \left[1 - \frac{2 R_S}{d} \cdot \frac{V_T}{V_S} \right]^N$$

Solve this equation for N to get approximately:

$$N = \frac{\log(1 - P_K)}{\log \left[1 - \frac{2 R_S}{d} \cdot \frac{V_T}{V_S} \right]}$$

If the torpedo can travel 5 times as fast as the enemy submarine (i.e.,

$\frac{V_T}{V_S} = 5$), $R_S = 5$ nautical miles, $d = 1500$ nautical miles, and system effectiveness is set at $P_K = 0.9$, the required number of search torpedoes is

$$N = \frac{\log(0.1)}{\log(0.967)} = \frac{1}{0.0146} = 68$$

For a sweep distance of 3000 nautical miles the number required is

$$N = \frac{\log(0.1)}{\log(0.98)} = \frac{1}{0.009} = 110.$$

If the lock-on radius of the torpedo homing device can be increased to

10 nautical miles, or the torpedo can travel 10 times as fast as the submarine (i.e., R_S or $\frac{V_T}{V_S}$ are doubled), the number of torpedoes required for 1500 and 3000 nautical mile sweeps are 33 and 68 respectively.

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This simple (very rough) calculation illustrates the significance and approximate role of some of the system parameters. Relative velocity of torpedo and target submarine is important. The number of search torpedoes required is almost inversely proportional to $\frac{V}{T}$; also, approximately inversely proportional to $\frac{R}{S}$. (Intuition suggests that system effectiveness depends upon N , V_T , V_S , d and R_S .) The foregoing calculation serves to indicate the nature of this dependence and to give approximate values of N for various values of some of the obvious component performances and operational parameters.

The numbers 68/33 and 110/68, for numbers of torpedoes required to kill 9 out of 10 attacking submarines, taken alone, do not provide comparative interpretations, except perhaps to indicate that an effective defense seems possible, assuming, of course, that components can be designed to operate reliably with the performances presumed by the values taken for R_S , V_T , and V_S . More will be said, later, about component performances and the related research and development problems.

However, more understanding of the potential of NAUCRATES can be obtained by comparison with conceivable alternative defense systems expressed in comparable simple terms.

Suppose that the defense against submarines is to be obtained by placing stationary, atomic mines along the sweep path, which have the property that, if a submarine approaches within a distance R_S to a mine, the presence of the submarine is detected and distinguished from other

- 110 -
~~SECRET~~

Appendix "C"
IDA-ARPA S-1

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objects, the mine is detonated and has a nuclear yield sufficient to destroy the submarine. Then for a kill probability of 0.9 and for R_s equal to 5 and 10 nautical miles, the approximate atomic yields required for the mines are 1.2 MT and 5.5 MT respectively, while the yield needed for NAUCRATES, if used in an attack mode, would be in the very low kiloton range. The number of mines needed for defense lines of length $d = 1500$ and $d = 3000$ nautical miles are 135/68 and 270/136 respectively, corresponding to an R_s of 5/10 nautical miles. In these terms the search torpedo compares very favorably. For the purely reconnaissance mode, this comparison may still be valid, and even more favorable, if the positive detection radius of stationary posts is not greater than the homing detection radius of the search torpedo - which is likely, because the homing operation involves an integration of information. Also, fixed posts may be more vulnerable to destruction.

Consider still another comparison, by supposing that submarines are posted underwater in fixed positions on the defense line, and equipped with a missile which can be fired out of the water along a ballistic air path to an underwater target at remote distance (e.g., sub-roc). If the effective target location range is R_s nautical miles, giving the larger defensive submarine vehicle the benefit of sufficiently accurate target identification and location at the homing range of NAUCRATES, and, perhaps, using larger warhead nuclear yields than that required for the search torpedo, the number of stationary picket submarines required for a kill probability of 0.9 is the same as that for the mines. Again,

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the nuclear-powered, hydrojet, search torpedo compares favorably, even if the effective target location range of the defensive submarine is taken as $2 R_s$, because the greater speed of the torpedo makes it potentially a better reconnaissance vehicle.

None of the foregoing comparisons adequately establish the system effectiveness of NAUCRATES, but they do suggest that it is worthwhile to undertake a detailed analysis of the system, by extending the consideration of relevant parameters, defining both performance of components and operational characteristics. Also, integration of the weapon with friendly submarines deployed as defense centers should be considered. Then the desirability, directions and extent of research and development on nuclear hydrojet, homing and sensing devices, computers and navigation equipment can be evaluated.

Suggestions for Further System Study

The foregoing simple calculations were made for only one use of the proposed weapon (i.e., sweep along a defensive line) on a highly-idealized basis, assuming that the probabilities of survival across each of the N paths were independent. A more realistic calculation of system effectiveness is desirable, considering the various contesting strategies of submarine penetration and countermeasures, patterns of sweep paths and relative locations of torpedoes on the paths, with proper accounting made of operational difficulties. Also, it is essential that comparisons be made with existing and alternative systems.

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For example, the enemy submarine may listen for the torpedo (undoubtedly it will be noisy), decoy it to search away from its location, and proceed to attempt penetration across the defended area, which may put additional requirements upon the detection and sensing equipment of the torpedo - or, it may be necessary to deploy the search weapon from defensive submarines or shore bases equipped with long-range listening devices, and program the torpedo to search in a specified area.

The peacetime reconnaissance role of the system merits detailed study and evaluation as to logistic complexity (for given effectiveness) in comparison with other systems. Does the proposed system provide a basis for constant defensive readiness which cannot be provided by present and proposed equipment, by seeking out and tracking submarines for long periods of time? What is the value of an extensive reconnaissance system, which itself may furnish striking power to the defense?

There will, undoubtedly, be interactions between the parameters described in the previous section. For example, range of detection may decrease with torpedo velocity. Such interactions should be introduced into a study of contesting submarine and torpedo strategies, so that evaluation may be made of the desired degree of increasing component performances. What advantages are obtained from higher and higher torpedo velocities?

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Suggestions for Research

Regardless of the merits of the proposed reconnaissance and anti-submarine defense system, certain areas of research are indicated, which seem worthwhile on general grounds.

a. Design of Nuclear Reactor Hydrojet Motor

Something like 15 megawatts of thermal energy will be required for speeds greater than 100 knots. It appears that about 50 liters of reactor volume will provide this power.

Considerable research on the design of the reactor power plant appears to be desirable. For the use intended, shielding is not essential. But high powers and long running times are needed. Studies on corrosion of reactor elements are required, particularly at the high running temperatures which may be encountered. How can the salts of the sea be kept from deposition on the reactor elements until emitted from the jet nozzle? Can sufficient power be obtained in a reasonable size to drive the torpedo at 200 knots - the answer to this question appears to be yes, but corroborating research is needed. In view of the tremendous advances in reliable, compact, long-range propulsion systems, emphasized by the recent dramatic NAUTILUS trip, it seems appropriate to initiate work on an ultracompact reactor of the type needed for NAUCRATES DUCTOR.

b. Hydrodynamic Control

At speeds better than 100 knots, the degree of cavitation will be such that the torpedo may be largely traveling in a bubble. What

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shapes may be used to minimize the control problems? Can jets be used? How are suitable control surfaces obtained? These questions suggest extensive hydrodynamic studies for very fast traveling submerged bodies.

c. Flow Noise

At the speeds contemplated, the dominant noise appears to be flow noise. Research on the flow noise associated with very fast traveling submerged shapes is needed. What are the characteristic levels and frequencies? Also, since the torpedo may be almost a fully cavitating body, what are the noise characteristics associated with this cavitation?

d. Homing Mechanism

If sonar is contemplated for the homing device, which seems likely, many problems arise. What vibrations are imparted to the transducer? Can it operate in the presence of the flow and cavitation noises associated with very fast traveling torpedoes? Must there be frequent short intervals of low-speed listening? Are the variations of flow and cavitation noises sufficiently random to be integrated out of the return signals received by the homing sonar? What size of transducer is needed to give desired homing ranges? None of these problems appear to be insurmountable, but extensive research is needed for their solution, and these studies should be closely integrated with those suggested in b. and c. above.

e. Navigation

The response times required appear to fall within the current

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and near future state of the arts on inertial devices, particularly if the speed of the torpedo is decreased during the homing operation.

f. Computer

Considerable research is indicated for the computer control system. The exact characteristics will depend upon the operations to be performed, and the possible functioning of this system has been indicated above in the section on supporting equipment. The effects of the radiation field of the reactor on the computer components need to be studied.

In all of these research areas some work has been done, with the exception, perhaps, of the computer. But the research effort appears to need considerable extension. The Ordnance Research Laboratory and the Underwater Sound Laboratory of the Navy are doing research on Flow Noise and Homing Sonars. Aerojet has done work on chemical hydrojet for the Navy. But these efforts need considerable extension to meet the performances proposed for NAUCRATES. Oak Ridge has done considerable work on small reactors, but not related to salt water hydrojets. The writer is not aware of any research being done on the computer or the hydrodynamic control problems of almost fully cavitating bodies.

It is suggested that existing Naval contractors and facilities be supported in extending their work to cover the research areas indicated above. Oak Ridge may be asked to do work on the reactor.

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Specific Recommendation:

The most advanced thinking at AEC national laboratories and elsewhere on ultracompact reactors should be sought out by the appropriate agency and used to make preliminary conceptual design studies of a 100-knot to 250-knot hydrojet torpedo, with a view to early initiation of further appropriate supporting research and evaluation of a weapons system built on such torpedoes, for an antisubmarine shield about the U. S. and for other military purposes.

Ronald W. Shephard

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D. PARTICIPATION IN PROJECT 137

D-1. MEMBERSHIP OF PROJECT 137

- Dr. Robert Charpie, Associate Director, Oak Ridge National Laboratory,
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- Mr. N. Christofilos, Group Leader, Radiation Laboratory, University
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- Dr. Glen Fowler, Director of Research, Sandia Corporation
Albuquerque, New Mexico
- Dr. Paul Garabedian, Professor of Mathematics, Stanford University,
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leased for the time of this study
by the Office of Naval Research,
London Branch, with which he is
at present serving on leave from
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- Dr. Marvin Goldberger, Professor of Physics, Princeton University,
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- Dr. Thomas Lauritzen, Professor of Physics, California Institute of
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- Dr. Nicholas Metropolis, Professor of Mathematics, Institute for
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Dr. John A. Wheeler, Professor of Physics, Princeton University,
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Dr. Joachim Weyl, Chief Scientist, Office of Naval Research

Col. Taylor Drysdale, Division of Advanced Planning, U. S. Air Force

Dr. Orr Reynolds, Office of the Assistant Secretary for Research
and Engineering

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D-2. BRIEFINGS

The following list is based upon the advance program plus minor changes and therefore does not reflect all of the last minute changes made in the program nor list all who participated, especially those who helped by way of special visits and providing special data.

14 July

OPENING SESSION

Remarks by Mr. Roy Johnson, Director, ARPA; Maj. Gen. James McCormack, IDA; Dr. Albert G. Hill, WSEG; and Prof. John A. Wheeler, Princeton.

Key Defense Problems - RAdm J. T. Hayward, ACNO (R&D)

ANTISUBMARINE WARFARE

USN Operational Capabilities in ASW - RAdm J. E. Weakley, ASW Readiness
Task Force Alfa Operations - RAdm J. S. Thach, Commander TFA
ASW R&D - Cdr C. E. Bishop, ONR
Proposed Approach to ASW - Prof. F. V. Hunt, Harvard
(also VAdm W. G. Cooper,
VAdm F. T. Watkins, Dr.
Paul Siple Capt Richard Holden)

15 July

ARPA Program - Dr. Herbert York, ARPA
Problems of National Defense - Dr. A. G. Hill, WSEG
Issues Facing Army R&D - Dr. William H. Martin, OSA R&D

HOW CAN MASSIVE QUANTITIES OF FUEL BE PROVIDED FOR FIELD USE

Future Army Organization and Requirement - Lt. Col. W. K. Bennett, ODCS, for Army
Superior Energy Sources - Col. C. W. Clark, Chief of ORD

- 139 -

Appendix "D"
IDA-ARPA S-1

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16 July

Major Issues Facing Air Force R&D	-	Mr. Richard Horner, SAFRD
Warning and Response	-	Maj. Gen. J. H. Walsh, USAF, Asst. Chief of Staff for Intelligence

BALLISTIC MISSILE AND ADVANCED PROBLEMS

Urgent Ballistic Missiles and Advanced Problems	-	Col. Edward Hall, AF EM Div.
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17 July

Air Defense in an Electronics Countermeasures Environment	-	Cdr John G. Fisher, WSEG
Nuclear Icebreaker	-	Dr. Allen Vine, Woods Hole Lab.

SUBMARINE COMMUNICATION

POLARS Communication Problem	-	Capt. J. D. Veazey, SP Project
VA/SSK Communication and Identification	-	Capt. R. C. Lynch, Cmdr. SD Group 2

18 July ARMY COMBAT SURVEILLANCE AND COMMUNICATIONS

Army Communications and Target Acquisition	-	Col. George Wertz, USACSA
Critical Requirements, World-wide Communications	-	Mr. Clifford D. May, SIG
Communications in a Mobile Army	-	Mr. H. Farmer
Application of Neural Processes to Communications	-	Dr. D. McK. Rioch, Walter Reed

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21 July

MEN IN BATTLE

Battlefield Surveillance and Other Urgent Problems	-	Lt. Gen. Arthur G. Trudeau, CRDUSA
Experimental Development of Tactics and Doctrine	-	Brig. Gen. Gibb, CDEC
Combat Simulation, War Gaming	-	Dr. Phillip Lowry, ORO
Human Factors	-	Dr. Lynn E. Baker, OCRD

22 July

Urgent Problems of Army Basic Research	-	Dr. Ellis Johnson, ORO
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NEW FORMS OF WARFARE

CW and BW Uses	-	Maj. Gen. W. M. Creasy, CWS
Psychochemical Agents and Antidotes	-	Dr. Silver, CW Laboratories
Special Devices	-	Dr. Iben Browning and Dr. David C. Williams, Sandia Corporation

23 July

DEFENSE

Hardening; Sustained Capabilities; Recuperation	-	Dr. Herman Kahn, Rand Corp. (with Dr. A. J. Clark, Dr. L. D. Berkovitz and Dr. H. Rowen)
Urgent Unsolved Problems of Civilian Defense	-	Dr. Lauritsen Taylor, National Academy of Sciences Committee on Civilian Defense (with Dr. Richard Park and Dr. Shea Kruegel)
Is Research Adequate in Non-Military Defense?	-	Mr. Gerhardt Fleiken, NASCCD and John Hancock Mutual Life Insurance Company

24 July

ARPA PROBLEMS

Space	-	Mr. David A. Young, ARPA
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- 141 -

Appendix "D"
IDA-AITA S-1

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Solid Fuel Propellants - Dr. John F. Hinkley
AICM - Dr. Richard D. Boll

25 July

ARMY AND NAVY

Problems of Defensive Mine Warfare - Capt. F. J. Lathan, USA
New Propulsion and Ball Concepts - Col. L. V. Howell and Mr. Frankenberger, USAF

26 July

ARMY AND NAVY

The Early Warning Problem - Dr. A. J. Hill, USMC
Reconnaissance and Early Warning - Dr. Duncan E. MacFarlane, Corp., Chm., Res. Div.
Special Effect - Mr. H. Christofide, Laboratory, Laramie

Report from AF Woods Hole Group - Prof. F. Seitz, USAF
Project River Styx - Signal Corps report, Fort Monmouth

28 July

"Big Dish" - Problems and Possibilities - RADM J. E. Hayward, USAF

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